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Characterizing and Controlling Urban Runoff through Street and Sewerage Cleaning

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Characterizing and Controlling Urban Runoff Through Street and Sewerage Cleaning

by

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Cooperative Agreement CR-805929

Project Officer

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This study was conducted
in cooperation with the
Storm and Surface Water Utility
Bellevue, Washington 98009

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16. ABSTRACT

A series of projects conducted from 1978 through 1983 in Bellevue, Washington, to investigate Bellevue's urban runoff sources, effects, and potential controls. This report presents results of the project conducted by the City of Bellevue that was sponsored by the Storm and Combined Sewer Section of the U.S. EPA. The project lasted from 1980 to 1983 and was mostly concerned with urban runoff characterization and control by street and sewerage cleaning. This project completely monitored more than 300 urban runoff events in two residential areas during the project period. Flow-weighted composite samples were analyzed for a core list of important constituents. Complete flow monitoring results allowed detailed descriptions of urban runoff quality and quantity, and allowed estimates to be made concerning the contributions of flows and pollutants from different source areas. Street surface and sewerage particulates were also collected and analysed to determine the effectiveness of street and sewerage cleaning. Most of the heavy metals were determined to originate from street dirt, but street cleaning was found to only control urban runoff by a maximum of about ten percent. A special modified street cleaner was tested and found to be much more effective in removing the smaller sized street dirt that is washed off these streets by rains. Catchbasin cleaning twice a year was estimated to be about 25 percent effective, at the most.

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FOREWORD

The U.S. Environmental Protection Agency is charged by Congress with protecting the Nation's land, air, and water systems. Under a mandate of national environmental laws, the agency strives to formulate and implement actions leading to a compatible balance between human activities and the ability of natural systems to support and nurture life. The Clean Water Act, the Safe Drinking Water Act, and the Toxics Substances Control Act are three of the major congressional laws that provide the framework for restoring and maintaining the integrity of our Nation's water, for preserving and enhancing the water we drink, and for protecting the environment from toxic substances. These laws direct the EPA to perform research to define our environmental problems, measure the impacts, and search for solutions.

The Water Engineering Research Laboratory is that component of EPA's Research and Development program concerned with preventing, treating, and managing municipal and industrial wastewater discharges; establishing practices to control and remove contaminants from drinking water and to prevent its deterioration during storage and distribution; and assessing the nature and controllability of releases of toxic substances to the air, water, and land from manufacturing processes and subsequent product uses. This publication is one of the products of that research and provides a vital communication link between the researcher and the user community.

A comprehensive evaluation of the sources and control of urban runoff was conducted during a two-year study in Bellevue, Washington. This project was one of several cooperating studies that examined the effects of urban runoff on receiving water beneficial uses, the sources of problem pollutants and flows, and the control of urban runoff in Bellevue. The unique Bellevue rain conditions enabled another urban runoff perspective to be obtained. Much data was also obtained on urban runoff characteristics and the washoff of street surface particulates during rains. These data allowed simple relationships between rain conditions and contributing source areas to be developed.

Francis T. Mayo
Director
Water Engineering Research Laboratory

ABSTRACT

A series of projects were conducted from 1978 through 1983 in Bellevue, Washington, to investigate Bellevue's urban runoff sources, effects, and potential controls. These projects were conducted by the City of Bellevue, the U.S. Geological Survey, the University of Washington, and the Municipality of Metropolitan Seattle. This report presents results of the project conducted by the City of Bellevue that was sponsored by the Storm and Combined Sewer Section of the U.S. EPA. This project lasted from 1980 to 1983 and was mostly concerned with urban runoff characterization and control by street and sewerage cleaning. This project completely monitored more than 300 urban runoff events in two residential areas during the project period. Flow-weighted composite samples were analysed for a core list of important constituents. Complete flow monitoring results allowed detailed descriptions of urban runoff quality and quantity, and allowed estimates to be made concerning the contributions of flows and pollutants from different source areas. Street surface and sewerage particulates were also collected and analysed to determine the effectiveness of street and sewerage cleaning. Most of the heavy metals were determined to originate from street dirt, but street cleaning was found to only control urban runoff by a maximum of about ten percent. A special modified street cleaner was tested and found to be much more effective in removing the smaller sized street dirt that is washed off these streets by rains. Catchbasin cleaning twice a year was estimated to be about 25 percent effective, at the most.

This report was submitted in fulfillment of Cooperative Agreement No. CR-805929 by the Storm and Surface Water Utility, Bellevue, Washington, under the sponsorship of the U.S. Environmental Protection Agency. This report covers a period from September 1980 to September 1983, and work was completed as of September 1983.

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SECTION 1
INTRODUCTION

The Bellevue urban runoff program is one of about 30 urban runoff projects being conducted throughout the country as part of the Nationwide Urban Runoff Program (NURP) for the U.S. Environmental Protection Agency (EPA). The Bellevue program is made up of four different coordinated projects. These include projects conducted by the U.S. Geological Survey (USGS) (funded by the USGS and NURP - the Water Planning Division of the EPA), the University of Washington (funded by the Corvallis Lab of the EPA), Seattle METRO, and the City of Bellevue (funded by the Storm and Combined Sewer Section of the EPA and the City of Bellevue). The project described in this report was conducted by the City of Bellevue.

A major task in Bellevue's project included monitoring the quality and quantity of stormwater runoff from two urban basins in the City of Bellevue. Street surface particulate samples were collected in these two basins, along with selected storm drainage sediment samples. The City of Bellevue conducted various street cleaning operations in the two test basins. The USGS (Ebbert, Poole, and Payne, 1983, and Prych and Ebbert, undated) also monitored storm runoff quality and quantity in these two test basins; they used different sampling techniques to monitor fewer storms, but in more detail. The USGS monitored rainfall and dustfall quality and quantity along with the performance of a series of detention basins at a third Bellevue test site (148th Avenue SE). The USGS and the City of Bellevue projects were carefully coordinated to enable all objectives to be met with minimum interference. The Seattle METRO project (Galvin and Moore, 1982) involved collecting urban runoff and other urban water and dirt samples for priority pollutant analyses. The City of Bellevue project was also coordinated with the METRO project to supply the urban runoff and street surface particulate samples for the priority pollutant analyses. The University of Washington's projects (Pedersen, 1981; Richey, 1982; and Scott, Steward, and Stober, 1982) investigated receiving water conditions near the Bellevue test basins and in other locations unaffected by urban runoff. The University of Washington project studied physical, chemical, and biological qualities of various receiving waters to identify impacts associated with urban developments on receiving water quality. Therefore, a substantial amount of information concerning Bellevue's urban runoff conditions and effects is available from these four associated projects. A summary report prepared by Pitt and Bissonnette (1983) reviews all these separate project reports and presents overall Bellevue urban runoff conclusions.

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OBJECTIVES

The project conducted by the City of Bellevue included objectives to satisfy the Nationwide Urban Runoff Program, the EPA's Storm and Combined Sewer Section, Region X of the EPA, and objectives specific for the City of Bellevue's Storm Drainage Utility . The project objectives are described below:

1) The principal project objective was to determine the effectiveness of street cleaning in controlling urban runoff pollutants in Bellevue. Several other projects have been conducted in other parts of the country previous to this project. Several of the other NURP projects are also currently evaluating street cleaning under a variety of climatic and geographical conditions. The Bellevue climatic conditions are unique in that the moderate amount of rainfall occurs relatively evenly throughout the year, with no long periods without any rain. The erosion potential of undisturbed areas is low. From previous studies, it is known that the street surface particulate loadings in the Pacific Northwest are naturally low and the urban runoff is of relatively high quality. These conditions contrast with the conditions for most of the comprehensive street cleaning management projects conducted elsewhere, especially in the San Francisco Bay Area where the rainfall is much less and is concentrated in fewer months of the year. The street loadings in other test cities can be quite high and the urban runoff quality can be quite poor. These Bellevue tests will therefore be useful in defining the applicability of street cleaning as an urban runoff best management practice under significantly different environmental conditions.

2) Stormwater quality and quantity characterization information obtained during this study is a significant contribution to the urban stormwater data base. Many urban runoff events were monitored during this project and the information obtained has been added to the STORET National Water Quality Data Base. The other NURP projects also have their runoff water quality and quantity data included in this data base. Site specific runoff/rainfall relationships for Bellevue have been obtained which will allow predictions of runoff changes due to urban development to be made.

3) Sources of urban runoff pollutants, especially street surface particulates, were also considered in this project. The effects of source area pollutant loadings on runoff water quality were examined.

4) The runoff water quality and quantity data and the street surface particulate loading data obtained can be used by the City of Bellevue as the beginnings of a more comprehensive data base for the whole city. This can support a water quality management plan as part of the City of Bellevue's Storm Drainage Utility.

METHODOLOGY

All elements of Bellevue's urban runoff project were coordinated with the three other local projects being conducted by the USGS, Seattle METRO, and the University of Washington. Early in the project planning phase, it was

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decided that two study areas should be selected. These areas, which are described in Section 3, are quite similar and fairly close. They are both totally urbanized with mostly single family housing. Their storm drainage systems were thoroughly mapped and investigated to ensure no cross-connections or illegal discharges. Each of the two basins drain at a single outfall and are each about 100 acres (40 ha) in size. A single stormwater monitoring station was located at the outfall of each of these basins for stormwater sampling. The sampling equipment selected for this project was capable of automatically sampling total storm flow-weighted composite samples for a broad variety of storm conditions. Appendix E describes the sampling equipment and procedures in detail. The information obtained from these automatic samplers and flow meters were supplemented by the sampling and monitoring equipment operated by the USGS at the same locations. As many storms as possible were sampled during the two-year study program at each of these two locations. Almost all storms having more than 0.1 inch (2.5 mm) of total rain and many of the smaller rains were completely sampled.

During the two-year project period, extensive street cleaning was conducted in either one or the other test basin, except for a several month period of time for basin calibration when no street cleaning operations were conducted. Intensive street cleaning was conducted during both wet and dry seasons in each basin. This allowed comparing the observed runoff water quality in each basin with and without street cleaning.

Street surface particulate samples were also obtained immediately before and after each street cleaning operation and intermittently during periods of no street cleaning. This resulted in a much more detailed description of the effects of the street cleaning operations on this potentially important urban runoff pollutant source area. Periodic samples of sediments from the storm drainage system were also obtained and analyzed to estimate the potential benefits of sewerage cleaning on improving urban runoff quality.

SECTION 2
SUMMARY AND CONCLUSIONS

There are three separate phases in designing an urban runoff control program. These include identification of the problem pollutants, determining the sources of the problem pollutants, and selecting the most appropriate control measures. The four Bellevue urban runoff projects addressed these issues.

IDENTIFICATION OF PROBLEM POLLUTANTS

The University of Washington study examined existing effects that urban runoff may be having on aquatic organisms. The other three Bellevue urban runoff projects all have important characterization aspects. These projects identify potential problem pollutants by comparing the observed runoff water quality with beneficial use water quality criteria and with concentrations found in other waste streams and receiving waters. This information can be used to identify which, if any, pollutants need to be controlled and to what extent. The unique assimilative capacities of the Bellevue receiving waters needs to be considered. Pollutants that are causing potential problems can be identified and appropriate control goals can be estimated.

The meteorological conditions at Bellevue are discussed in Section 4 and Bellevue urban hydrology conditions are discussed in Section 5 of this report. These two sections point out some of the special circumstances associated with Bellevue's urban runoff. Bellevue receives a moderately large amount of rain every year (about 35 inches, or 890 mm) with several summer months drier than the other months. However, the dry periods between rain events are quite small, even during the dry season. Dry periods of more than a week are quite rare, but may occur. Rains come on the average about once every two or three days throughout the year. Slightly more than 100 rains may occur per year, with each rain being quite small. Most of the rains are less than 0.25 inch (6.4 mm) in volume, although the largest rains monitored during this study were several inches. This is in sharp contrast to most other locations in the country. In the San Francisco Bay Area, where previous comprehensive street cleaning and urban runoff studies have been recently completed, the annual rainfalls are much less than in Bellevue, but the rains are typically larger in size. The interevent period in the San Francisco Bay Area is several days during the wet winter season, but can be several months during the summer. The total annual rainfall at Bellevue is similar to the total rainfall at some of the other NURP project sites in the country that are currently investigating the effects of street cleaning on urban runoff; however, the average rains in these other areas are much larger than the average rains in Bellevue, with significantly longer interevent periods (specifically Milwaukee and Winston-Salem).

The amount of rain that drains off an urban area as urban runoff is dependent upon many factors. These factors are discussed in Section 5 and include such things as soil moisture conditions, soil infiltration capacity, rain intensity, and rain duration. The moist soil conditions in Bellevue (due to the high frequency of rains) tends to increase the fraction of rain that occurs as runoff. However, the small volumes and the small intensities of each individual rain allows much of the water to infiltrate into the soil. For both study years and test basins, only about 25 percent of the rain that fell in the test basins left the basins as runoff. There was a substantial amount of scatter in this value, but the smaller rains typically had the smallest Rv (the ratio of unit area runoff to rainfall) values (rains of about 0.1 inch, or 2.5 mm, had Rv values of about 0.1 for the dry season and about 0.2 for the wet season), while the largest rains had larger Rv values (rains of about 2.5 inches, or 64 mm, had Rv values of about 0.2 to 0.3 during the dry season and about 0.3 to 0.4 during the wet season).

Base flows were also monitored and sampled during this project. An important amount of the total urban water flows in both of the test basins occurred between rains, as baseflow. The base flow in the Surrey Downs basin accounted for about 25 percent of the total urban flow, while the base flow in Lake Hills was only about 12 percent of the total urban flow. Observed urban flow and quality variations were much less than found in more arid areas. This has a major influence on the effects of urban runoff. Immediate urban runoff effects (during storm flows) are mostly related to fast and major changes in receiving water quality and quantity (as in a slug flow situation). If the flows and quality do not change radically, the receiving water aquatic organisms do not experience as much stress because the existing organisms have already adjusted to a long-term degraded condition.

The runoff water quality data presented in Section 6 shows that the observed Bellevue runoff water quality was much better than observed in many other locations. The baseflow quality, on the other hand, was much worse than expected. This was probably because the study basins were completely urbanized and the baseflows were mostly polluted percolated urban sheet flows from previous storms that were draining out of the surface soils. In basins with undeveloped upstream areas, the baseflow would originate mostly from nonurbanized upper reaches and would have much better quality. The urban hydraulic conditions in Bellevue allow the observed runoff water quality to be compared to beneficial water quality criteria. Typically, urban runoff should not be compared to water quality criteria because the published criteria were established for continuous discharges, while urban runoff is usually considered a slug discharge. However, as previously noted, the baseflow and urban runoff qualities in Bellevue do not differ greatly. Therefore, as an approximation to identify potential problem pollutants, the beneficial use water quality criteria for aquatic life, published by EPA (1976), was compared with the observed Bellevue urban runoff quality. It was found that direct receiving water effects from urban runoff may not be significant for most rain events (except possibly for ammonium and nitrate nitrogen). Most of the Bellevue urban runoff water quality problems are

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expected to be associated with long-term effects caused by settled organic and inorganic debris and particulates. This material can silt up spawning beds in the Bellevue urban streams and possibly introduce high concentrations of toxic materials directly to the sediments. Identified potential long-term problem pollutants are settleable solids, lead, and zinc. The University of Washington studies (Pedersen, 1981; Richey, 1982; and Scott, Steward, and Stober, 1982) and the Seattle METRO study (Galvin and Moore, 1982) will address this issue in more detail.

SOURCES OF PROBLEM POLLUTANTS

The second phase in designing an urban runoff control program is to determine the sources of the problem pollutants in the watershed. An understanding of where the problem pollutants accumulate in the catchment is needed before appropriate controls may be selected. Sections 5 and 6 discuss the sources of urban runoff flows and pollutants in the test basins. In Section 5, which deals with urban runoff flows, it was found that the impervious surfaces (including street surfaces, driveways, parking lots, and rooftops) can account for almost three-fourths of the runoff flows in both basins during any season. There are few vacant lots or parks in the test basins, so the remainder of the urban runoff flows originates from landscaped front or back yards. For very small rains (<0.1 inch, or <2.5 mm), however, street surfaces alone contribute from one-half to three-fourths of the total runoff flows. Driveways and parking lots make up the remainder for the smallest rains. During these very small rains, rainwater infiltrates into the soil in the pervious areas, with runoff primarily originating from the impervious areas. The contribution from street surfaces decreases with larger rains and remains fairly constant for rains larger than about 0.1 inch. The observed variation of runoff sources from different areas as a function of rain quantity is smaller than for locations previously studied (Ottawa, Ontario; Pitt, 1982 and Castro Valley, California; Pitt and Shawley, 1981).

Because of variations in sheetflow quality from the source areas during runoff events, the contributions of pollutants from each source differs from the contributions of runoff flows. Using some sheetflow runoff quality data obtained previously in other locations, and with an understanding of the local Bellevue conditions, estimates of pollutant contributions from these different source areas were made in Section 6. It is estimated that total solids (for most rain events) originate mostly from the back and front yards in the test basins and that street surfaces contribute only a small fraction of the urban runoff total solids discharge. Street surfaces, however, are expected to make up most of the lead, zinc, and COD contributions to the urban runoff. Phosphates and total Kjeldahl nitrogen are mostly contributed from street surfaces, driveways, and parking lots combined. Back and front yards make up slightly less than half of these nutrient contributions to the outfall. Therefore, street cleaning operations cannot be expected to significantly improve the urban runoff total solids loadings or concentrations. If the available street surface particulate loadings could be reduced by one-half, then many of the other pollutants may be reduced by about 25 percent at the outfall.

Section 7 discusses in detail the observed street surface particulate contaminant loadings, including accumulation and deposition rates. The Bellevue street surfaces included in the tests were relatively clean when compared to other locations. However, this is mostly due to the frequent Bellevue rains. The initial accumulation rates (assumed to be equal to the deposition rates) in the test areas was estimated to vary between three and 20 (with an average of about ten) lbs/curb-mile/day (between 0.9 and 5.7, with an average of about 2.8, g/curb-meter/day). This is comparable to the accumulation rates observed in other locations for smooth streets in good condition. The accumulation rates may be several times these values for streets in poor condition. The Bellevue streets never have an opportunity to become extremely dirty, due to the moderately low accumulation rates and the frequent rains. The frequent rains do not remove all of this material from the streets. From 200 to 400 lbs/curb-mile (57 to 110 g/curb-meter) of street surface particulates remain on the streets after storms of about 0.25 inches (6.4 mm) or greater. This initial loading value is similar to initial loading values observed in other locations. These initial loading values would be much greater for streets in poor condition than for very smooth streets in good condition.

The observed chemical concentrations associated with the Bellevue street surface particulates are also not that unusual when compared to other locations throughout the U.S. Again, the main difference for Bellevue is that the frequent rains do not allow the street surface particulate and contaminant loadings to reach extremely high values. The amount of street surface particulates that can be removed from Bellevue streets by rains is limited to a fairly narrow range. Infrequent large rains can remove much more of the street surface particulates than the more common, smaller rains. The texture of the street itself has a tendency to trap a certain amount of the particulates. As noted in the following paragraphs on the selection of control measures, typical street cleaning equipment also cannot remove the particulates that are "protected" by the street texture. Rains and street cleaning equipment are effective in removing the street surface particulates only above this base level value (of between 200 and 400 lbs/curb-mile, or 57 to 110 g/curb-meter).

Periodic samples of Bellevue storm drainage particulates were also collected from the two test basins during the project. There were about twice as much polluted sediments in the storm drainage systems at any one time as there were on the streets. However, the flushing of most of the sewerage sediments out of the drainage systems and into the receiving waters would probably not occur except for large storm events. Smaller storms probably remove a small fraction of the sewerage sediments. The collected data was too sparse to estimate the removal of sewerage sediments by storms.

SELECTION OF CONTROL MEASURES

The last phase in developing an urban runoff control program is to examine the different measures that can be used to control the identified problem pollutants in the different source areas. The control measures that are appropriate for the source, accumulation areas, or outfall must be

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identified. Street cleaning can only operate on streets and parking lots (and possibly sidewalks and driveways); construction erosion control only affects construction areas; runoff storage and subsequent treatment can affect all source and accumulation areas. The effectiveness of the applicable control measures in reducing problem pollutant concentrations and yields at the outfall must be evaluated. When pollutants are removed from a watershed (such as by erosion control or by street cleaning), much more needs to be removed than the amount necessary to meet the discharge goal at the outfall. As an example, about ten pounds of a pollutant may be needed to be removed by street cleaning to prevent one pound of the pollutant from entering the receiving water. After the control measures' applicability and effectiveness values are known, the urban runoff control program can be designed. In order to meet water quality objectives, a combination of several different control measures may be needed. Complex decision analyses procedures may be necessary if multiple objectives are important.

Section 9 of this report evaluates the urban runoff data, dividing it into periods of intensive street cleaning and no street cleaning. Very little, if any, difference can be detected at the outfall based upon these two street cleaning programs. The most important reason why any potential changes were not detected are based on the variations in rainfall and subsequent runoff quality and quantity observed at the two basins. As noted in Sections 4 and 5, the rainfall variation at the two test basins can be greater than 25 percent most of the time. This 25 percent difference in rainfall corresponds to a much greater difference than 25 percent in runoff yield. This is because larger rains result in a larger percentage of the rain occurring as runoff. Therefore, runoff improvements measured at the outfall at a level substantially greater than 25 percent would be necessary to detect an improvement under most of the rain conditions during this study period. Sampling, laboratory, and analyses errors also contribute to masking any effect that may have occurred. The analyses included in Section 9 attempted to eliminate most of these flow differences using appropriate transformation and analytical techniques. The data was separated by season and street cleaning program. The intensive street cleaning program was rotated between the test and control basins on a seasonal basis to eliminate some of the differences associated with rain conditions.

Section 10 describes the effectiveness of the street cleaning equipment in removing street surface particulates. Street cleaning equipment cannot remove particulates from the street surface unless the loadings are greater than a certain residual amount. This value was about 500 lbs/curb-mile (140 g/curb-meter) in the test basins. If the initial street surface loading values are smaller than this value, some of the street surface material can be "loosened", but not removed. The street surface particulate loadings after the street cleaning operation may then be greater than the initial values.

The frequent rains may be more effective than street cleaning in keeping Bellevue streets clean. The street surface loadings after rains were between 200 and 400 lbs/curb-mile (57 and 110 g/curb-meter), but the street cleaning equipment could only remove street surface particulates down to about 500 lbs/curb-mile (140 g/curb-meter). If the street cleaning was conducted more frequently than the rain intervals, then street cleaning may result in

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cleaner streets.

The intensive street cleaning program that was conducted during these tests can result in about a 25 percent reduction in street surface loadings when compared to no street cleaning. If the street surface contributes about half of the total source for a specific pollutant, intensive street cleaning may only remove about ten percent of the pollutant yield at the outfall. Typical runoff reductions by street cleaning are estimated to be about five to ten percent. As noted previously, it would require a fairly substantial reduction in discharge yield to be statistically significant based upon outfall measurements. The effectiveness of street cleaning equipment in controlling urban runoff is very site specific. If the street surface loadings were much greater than the breakeven street cleaning point, and there were less frequent rains, street cleaning might control important fractions of the total urban runoff flow. Street cleaning in Bellevue may not be an appropriate urban runoff control measure, especially at a cost of about $20/curb-mile ($12.50/km). With such small potential improvements in urban runoff quality, other street cleaning benefits are more important.

Special tests were conducted using a modified regenerative-air street cleaner. It was demonstrated that this equipment was much more effective in removing the finer street dirt material than the regular mechanical street cleaner tested. This finer material can be washed from the streets by rains more easily than larger material. Therefore, urban runoff quality can be improved slightly more with the use of this modified equipment (to about ten percent reductions).

Sections 8 and 11 discuss the potential effects that sewerage cleaning may have on urban runoff control. The sewage inlet and catchbasin sediments had relatively constant accumulation rates after cleaning for about one year. After a year, the sediment volumes remained quite constant, with little effect on the runoff yield. A major rain event during the second year after cleaning did not result in any net average or total sediment loading change. Sewage inlet and catchbasin cleaning is therefore recommended on about an annual basis. This should result in annual total solids and lead storm runoff yield reductions of between ten and 25 percent. The other constituents studied (COD, TKN, TP, and Zn) may be controlled by between five and ten percent. More frequent cleaning would not increase these reductions, as the observed sediment accumulation rates appeared to be constant, until the constant volume value was obtained. Only about 60 percent of the available sump volumes were used for detention. Large sumps had less of their volumes utilized. Catchbasins with large sump volumes could be cleaned less frequently because they held larger volumes of sediments. Allowing pollutants to remain in a sump for long periods of time, however, may increase their solubilities, enhancing their washout potentials and making them more available to receiving water organisms.

SECTION 3
STUDY AREA DESCRIPTION

Figure 3-1 shows where the City of Bellevue is located in the Pacific Northwest. Bellevue is located on the other side of Lake Washington from Seattle, Washington, and is within commuting distance. Lake Sammamish borders Bellevue on the east. Bellevue receives about 35 inches (890 mm) of rain per year, while substantially greater amounts of rain occur on the Olympic Peninsula to the west and much smaller amounts of rain occur in eastern Washington to the east.

Figure 3-2 shows the locations of the Surrey Downs and Lake Hills catchments in the City of Bellevue. These two sites are located about three miles (5 km) apart and are each about 100 acres (40 ha) in size. They are both fully developed as mostly single-family residential areas.

The Surrey Downs basin is 95.1 acres (38.5 ha) in size and includes the Bellevue Senior High School in addition to single-family homes. Most of the slopes in the basin are moderate, with some steeper slopes on the west side of the basin. Table 3-1 shows that about 60 percent of the Surrey Downs basin is pervious. Back and front yards make up most of the land surface area in the basin, with streets making up a typical ten percent. The streets are generally in good condition with smooth to intermediate textures. There are a few locations where the curb needs repair. Westwood Homes Road and 108th Street do not have curbs. There is relatively little automobile traffic in the Surrey Downs basin and the on-street parking density is low. The storm drainage system discharges into an artificial pond located in an adjacent development. This pond discharges into Mercer Slough which eventually drains to Lake Washington and Puget Sound.

The Lake Hills catchment is 101.7 acres (41.2 ha) in size and contains the St. Louise Parish Church and School in addition to single-family homes. Lake Hills has a slightly larger percentage of pervious areas than Surrey Downs, but a slightly smaller typical lot size. The slopes in Lake Hills are also more moderate (with a few exceptions) than those found in Surrey Downs. The street surface and gutter systems are also similar to those in Surrey Downs. Most of the streets in Lake Hills also carry low volumes of traffic and have low parking densities, except for two busy roads that cross through the area. The Lake Hills storm drainage system outfalls into a short open channel which joins Kelsey Creek just downstream from Larsen Lake. Kelsey Creek also discharges into Mercer Slough and finally to Lake Washington and Puget Sound.

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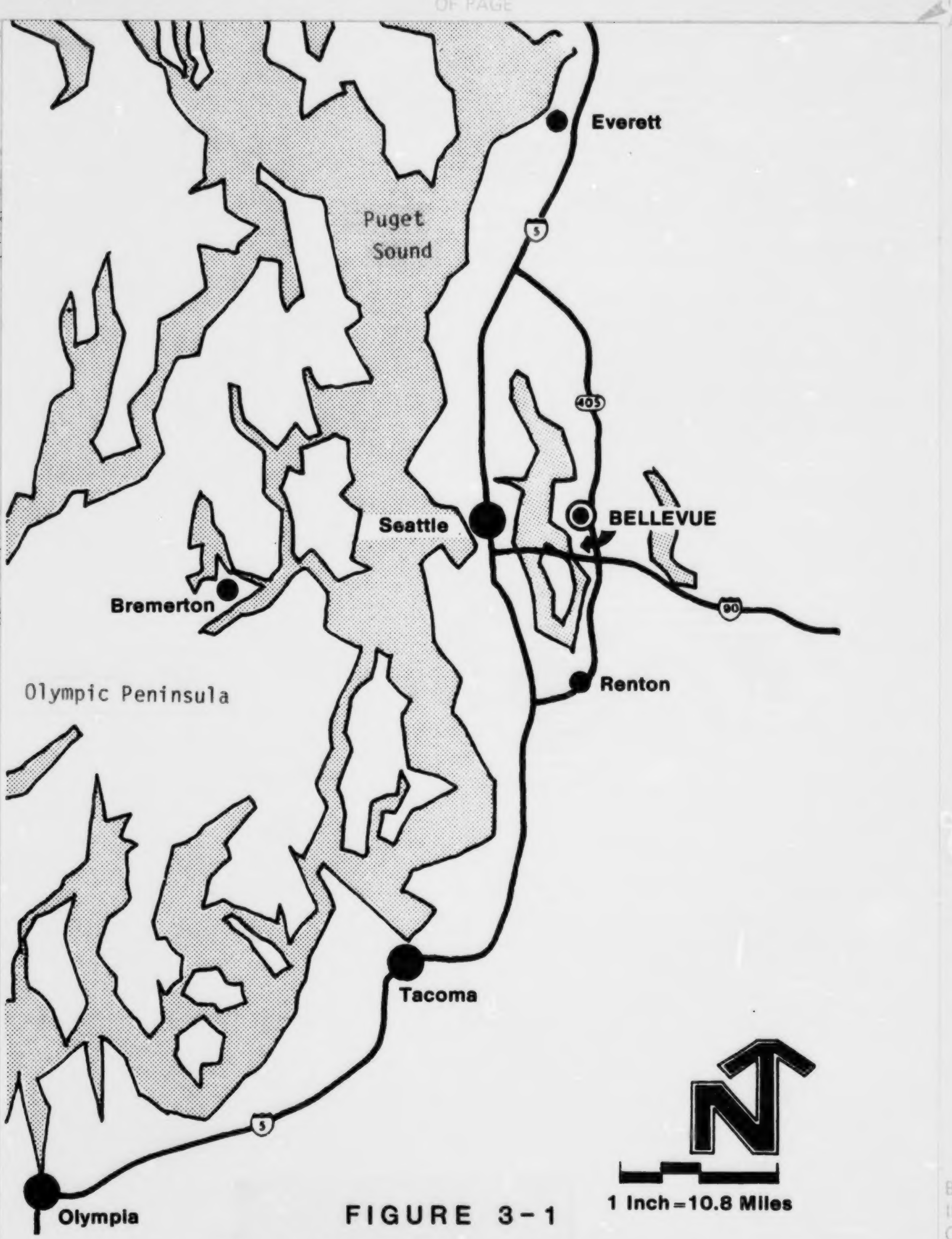
Everett
Puget Sound
5
405
BELLEVUE
Seattle
Bremerton
90
Renton
Olympic Peninsula
Tacoma
5
Olympia
N
1 Inch = 10.8 Miles

FIGURE 3-1

Northwest Washington State and the City of Bellevue

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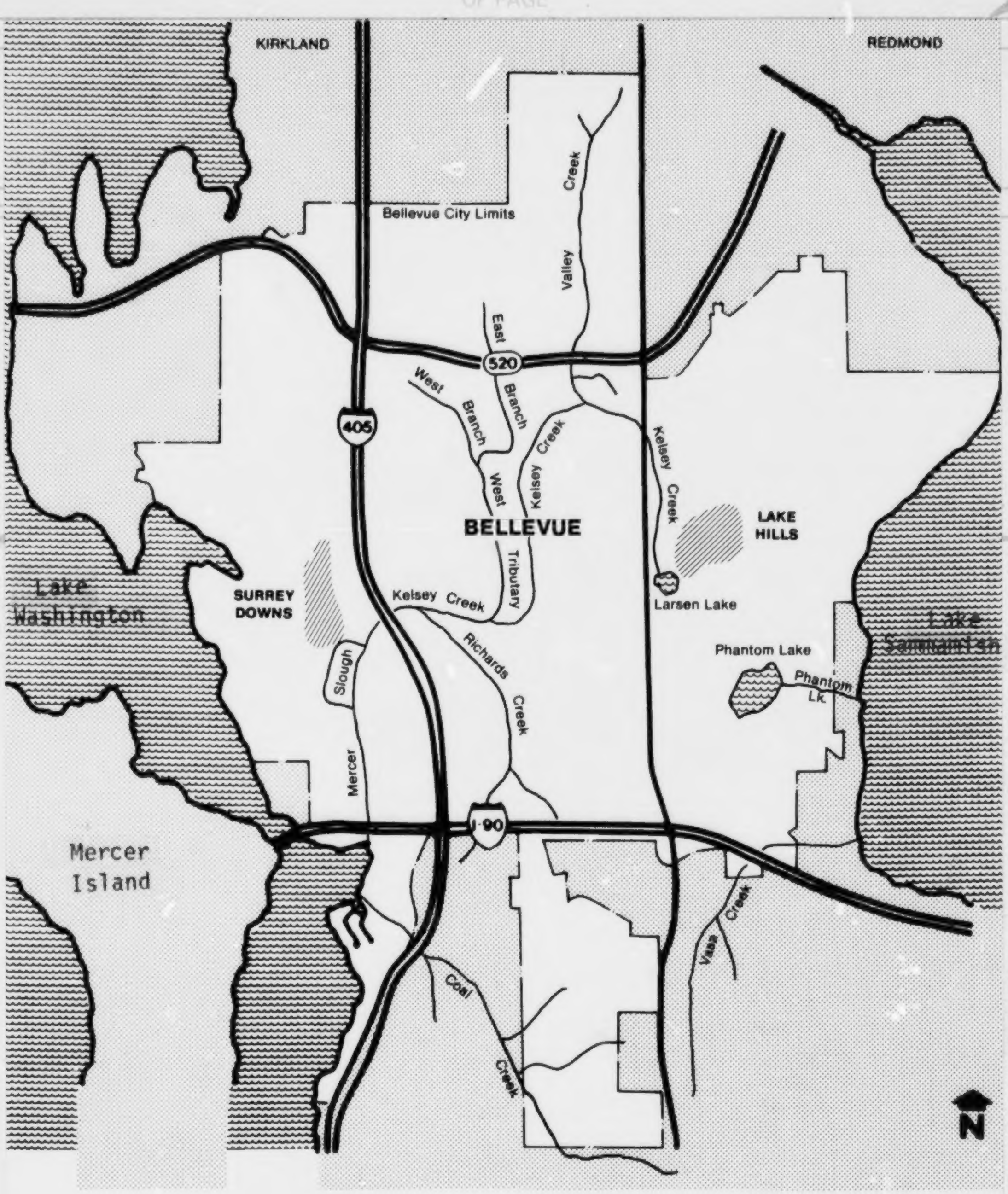
KIRKLAND
REDMOND
Bellevue City Limits
Valley Creek
East Branch
520
West Branch
405
West Branch
Kelsey Creek
Kelsey Creek
BELLEVUE
LAKE HILLS
Lake Washington
SURREY DOWNS
Kelsey Creek
Tributary
Larsen Lake
Phantom Lake
Phantom Lk.
Lake Sammamish
Richards Creek
Slough
Mercer
I-90
Mercer Island
Vasa Creek
Coal Creek
N

FIGURE 3-2

City of Bellevue, Washington
Stream System and Study Sites

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Table 3-1. SITE CHARACTERISTICS

	Surrey Downs		Lake Hills	
	10^6 ft^2	%	10^6 ft^2	%
Vacant	0.06	1.6	0	0
Parks	0.08	2.0	0.14	3.4
Backyards	1.45	37.1	1.52	36.5
Frontyards	0.89	22.8	1.01	24.4
Rooftops	0.67	17.1	0.79	18.9
Driveways	0.20	5.2	0.20	4.9
Parking Lots	0.15	3.9	0.01	0.2
Sidewalks	0	0	0	0
Streets	0.40	10.3	0.48	11.7
Total	3.90	100%	4.15	100%
Area (acres)	95.1		101.7	
Fraction Impervious	0.40		0.35	
Fraction Pervious	0.60		0.65	
# of Homes:	274		355	
Lot Size:	0.3 acre		0.25 acre	
Frac. Resid.	0.91		0.90	
Frac. Indus.	0		0	
Frac. Commer. & Inst.	0.06		0.07	
Frac. Open area	0.03		0.03	
Curb-miles of Streets	5.5(1)		7.0	

(1) Westwood Homes Road = 0.5 miles
108th Ave. = 1.5 miles
Cleaning Area = 3.5 miles

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A demographic survey was conducted in the Lake Hills and Surrey Downs catchments at the beginning of the project. Slightly more than three people per household were reported in both basins, while the population density per acre was about 12 in Lake Hills and about 9 in Surrey Downs (29 and 22 per hectare, respectively). Almost 25 percent of the households in Lake Hills had more than 5 people, while only about 14 percent of the Surrey Downs houses had that many people per household. More than half of the households in both basins did not have any dogs or cats, but the remainder of the households had one of each, or more. On the average, there was about one dog or cat per household. Slightly more than two cars per household were reported, with about ten percent of the households in each basin reporting four or more cars. About one-third of the households used unleaded gasoline while the remainder used leaded regular or leaded premium grades of gas. Most of the automobile oil was disposed properly in the household garbage, or recycled, but between five and ten percent of the households used oil to treat fenceposts, dumped it onto the ground or into the storm sewers. Most of the people carried their grass and leaves to the dump or put them in the garbage, and about one-third composted the organic debris on their lots. It was not possible to obtain adequate data on the quantity of fertilizers or pesticides that were used in the basins.

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SECTION 4
BELLEVUE RAIN CONDITIONS

One important prerequisite of any urban runoff control program is an understanding of the local rain conditions. In order to gain this understanding, the rain conditions during the period of study should be representative of long term conditions. The Bellevue monitoring program lasted for two years, during which fairly typical rains occurred. The probability of unusual rain conditions lasting for a long period of time is reduced compared to lasting for a short period of time.

Differences in rainfall quantities result in differences in runoff quantities. The differences in runoff quantities in turn produce differences in runoff yields. Therefore, abnormal rain conditions during an urban runoff study period will result in abnormal runoff quantity and quality data. Similarly, short term fluctuations or differences in rainfall conditions, of time or area (unusually dry or wet months, or areal rainfall variations), can result in unrepresentative runoff yield predictions.

The most important task of this project was to monitor the effectiveness of street cleaning operations. One element of this analysis involved the comparison of observed runoff quality conditions in study sites with and without street cleaning. If the rainfall conditions varied between test and control sites during a test period then the observed runoff yields might not be indicative of the control measures' effectiveness. This report section describes the rainfall conditions (including variations and differences) that occurred at the two Bellevue test areas during the two-year study period.

Rainfall monitoring equipment was located at each runoff monitoring station at Surrey Downs and Lake Hills. During parts of the study, additional rainfall monitoring gauges were located at other locations in and adjacent to these monitored basins. Rainfall monitoring began at the Lake Hills station in the middle of February, 1980, and about two weeks later at the Surrey Downs station. Rainfall monitoring was completed at the end of January, 1982, at both basins. Tables A-1 and A-2 in Appendix A summarize the monitored rains at both of these locations throughout the two year study period. More than 200 rains were monitored at each of these basins. Table 4-1 summarizes the rain conditions on an average monthly basis for both basins combined.

The total annual rainfall averaged about 37 inches (940 mm) with about 108 rain events per year. The year can be separated into dry and wet seasons with the dry season lasting from the first of March to the end of September. This dry season has monthly rain totals of less than about three inches (76 mm), while the wet season, lasting from the first of October to the end of

Table 4-1. AVERAGE LAKE HILLS AND SURREY DOWNS RAIN CONDITIONS DURING PERIOD OF STUDY (FEBRUARY 1980 THROUGH JANUARY 1982)

	Rain per month (in.)	Number of rain events per month	Rain per storm (in.)	Duration of each storm (hours)	Preceeding dry period (hours)	Average rain int. (in/hr)	Peak 30 min. rain int. (in/hr)	Season
January	3.6	11	0.33	12	53	0.03	0.09	wet
February	3.3	6	0.54	22	70	0.02	0.14	wet
March	2.6	9	0.30	14	68	0.02	0.11	dry
April	2.8	11	0.29	10	59	0.04	0.13	dry
May	1.6	9	0.19	8	72	0.03	0.10	dry
June	2.4	10	0.27	8	79	0.05	0.13	dry
July	1.2	3	0.39	8	115	0.05	0.14	dry
August	0.8	4	0.21	9	650	0.04	0.12	dry
September	3.0	8	0.38	11	81	0.05	0.19	dry
October	3.7	7	0.49	11	110	0.03	0.14	wet
November	5.6	14	0.40	12	37	0.04	0.15	wet
December	6.4	16	0.41	12	34	0.03	0.14	wet
Annual	37.0 (tot)	108 (tot)	0.34 (avg)	11 (avg)	120 avg)	0.04 (avg)	0.13 (avg)	---

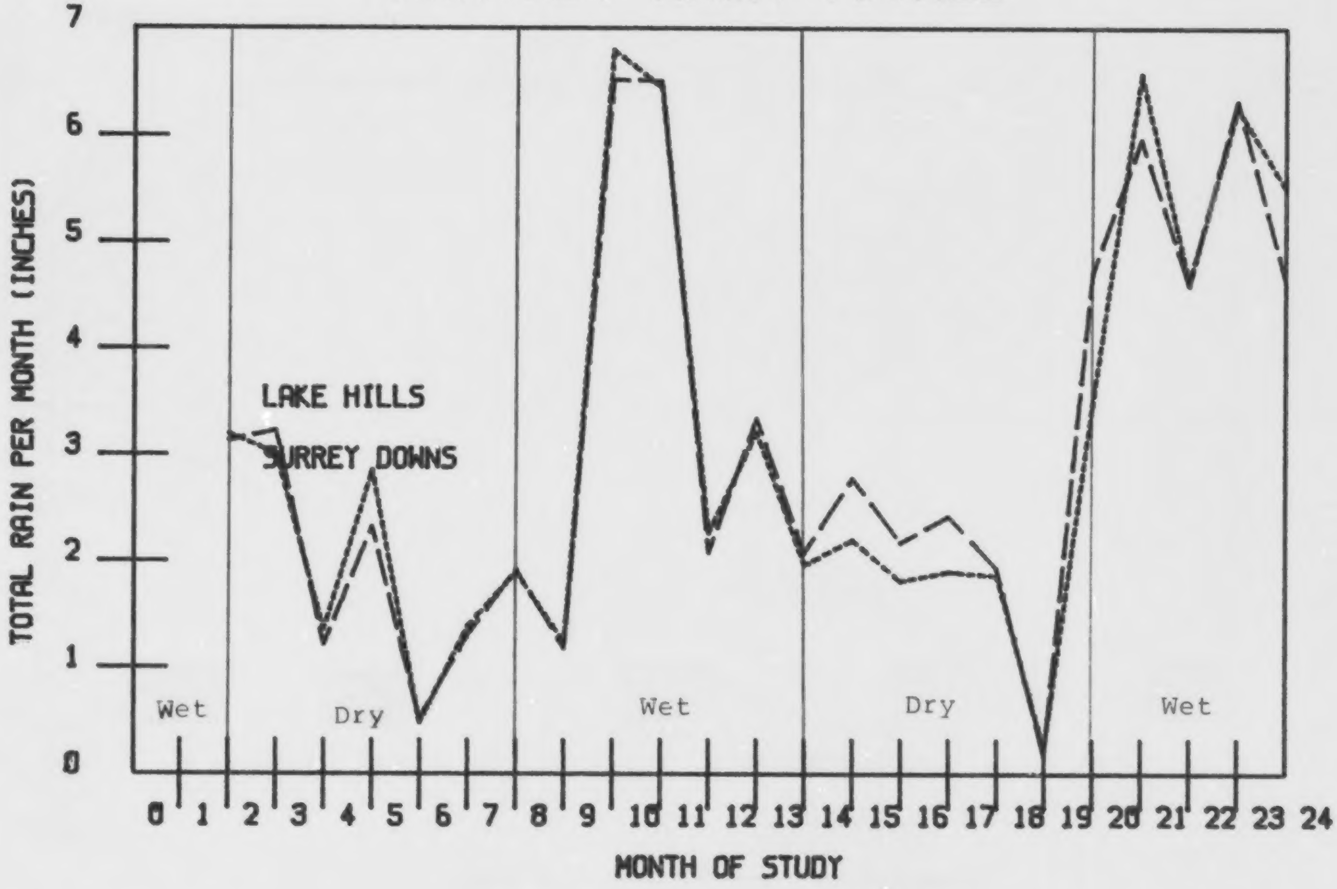
February, has monthly rain totals between three and 6.5 inches (76 and 165 mm). Each storm during the wet season had about twice as much rain as each storm during the dry season. The wet season rains also lasted about one and a half to two times as long as dry season rains. The maximum preceding interevent dry periods during the dry season were substantially greater than during the wet season, especially for July and August. The average and peak 30-minute rain intensities for both wet and dry seasons were quite similar. The average rain intensities were about one third of the peak intensities. When Tables A-1 and A-2 are examined, the overall ranges in observed conditions for any month are seen to have been quite large. The maximum storms during the wet season were typically about 1.5 inches (38 mm) while they were about 0.5 inches (13 mm), or less, during the dry season. These conditions compare relatively well with the rain period of April, 1975, through January, 1977, which was analyzed as part of the first Bellevue report. That previous period had an annual average rainfall of about 34 inches (870 mm), with about 60 storms per year. This earlier period included less than typical rain quantities. The wet and dry season divisions, however, were still the same as observed during this more recent study period.

The variation in monthly rain totals, as shown in Figure 4-1, shows that the first months of the two wet seasons studied (October and November) have more rain than the following months of the wet season. The latter months in the dry season (July and August) have less rain than the earlier dry season months. This results in a general saw-tooth pattern, where the rain total starts out low at the end of the dry season and then rises radically at the beginning of the wet season. The monthly rain totals then decrease with each succeeding month to a low point at the end of the dry season. During the first year, November was the wettest month, while during the second year, October was the wettest month. These wide variations in monthly rain characteristics, and the possibly repeating pattern of rains may be important in designing a street cleaning program that is much more intensive before these initial large rains of the wet season.

Most of the rain events that occurred during the study period were completely monitored at both the Lake Hills and Surrey Downs sites. Appendix Tables A-3 through A-5 summarize the observed rainfall characteristics for these two basins on a storm by storm basis. These tables present the observed total rainfalls, rain durations, and average and peak 30-minute rain intensities for both basins. Ratios of the rain totals observed at each basin were calculated. Duration ratios and differences in the start times for each rain event are also shown on these tables. A total of 165 paired storm events were monitored during this two-year study period. Lake Hills rain totals averaged 12 percent more than the Surrey Downs rains. The average duration of the Lake Hills rains was about 11 percent longer than for the Surrey Downs rains. The Lake Hills rains also started about 1/2 hour before the Surrey Downs rains. The ranges of the individual storm values, however, varied greatly. The total rain and duration ratios range from less than one-tenth to more than three times, while the time differences are as great as 16 hours. The following paragraphs discuss the major variations in rain characteristics at the two sites on a seasonal basis.

FIGURE 4-1

MONTHLY RAIN TOTALS



(from Feb. 1980 to Jan. 1982)

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Figure 4-2 shows the distribution of rain events and corresponding runoff volumes for both study sites and all study periods combined. Most of the rain events had less than 0.25 inches (6.4 mm) of rain and less than ten percent of the rain events had volumes greater than one inch (25.4 mm). When the rainfall quantities are considered, most of the rainfall is associated with rain events greater than about 0.6 inches (15 mm). The common small rains do not add up to much rain volume. Rains smaller than 0.25 inches (6.4 mm) accounted for less than 25 percent of the total rainfall volume, while about 30 percent of the total rainfall volume was associated with rains greater than one inch (25.4 mm).

The distribution of the runoff volume is also shown on Figure 4-2. Most of the runoff is associated with rains greater than 0.75 inches (19 mm) while the most common rainfalls of less than 0.25 inches (6.4 mm) produced less than ten percent of the total runoff. The relationships between runoff and rainfall are discussed in detail in Section 5. The weighted average Rv values (runoff/rain) for both of the study sites was about 0.25. This value means that about 25 percent of the rainfall left the watershed as surface runoff. Three-fourths of the rainfall either evaporated or entered the soil. Much of the rainfall entering the soil later left the study areas in the form of baseflow between runoff events. The rest of the infiltrated rainwater either recharged the underlying groundwater or was lost through evapotranspiration by plants.

Differences in observed rain quantities for the same storm periods for Lake Hills and Surrey Downs are shown on Figures 4-3 and 4-4. About half of the rains that were observed simultaneously at both basins had a difference in rain quantity greater than plus or minus 20 percent. This difference was much greater for the small rain events than for the larger rain events. As an example, several rain events measured about 0.3 inch (7.6 mm) in one basin while only measuring 0.1 inch (2.5 mm) in the other basin. This can result in much more than a three to one difference in the observed runoff yields. As described in Section 5, the smaller events result in a smaller fraction of runoff than larger events due to infiltration and surface detention/storage. When the resultant runoff yields from the two basins are compared for a specific storm, differences in observed rains may be much more important than differences in control measure applications. This is important for the discussions in Part 4 on control measure effectivenesses.

Figures A-1 through A-6 show the average monthly rainfall parameters for two different basins. In most cases, the two basins have very similar patterns in parameter trends, but the individual values for a specific rain event may vary significantly.

Figures A-7 through A-9 present scatter plots of Lake Hills and Surrey Downs rain totals, durations, and peak intensities transformed by natural logarithms. This transformation allows certain statistical tests to be made if the resulting distribution of data points is normal (having a "bell" shape). It also reduces the apparent importance of extreme values (helps to identify real "outliers"). Figure A-7 plots the natural log of the Lake Hills rain quantities against the natural log of the Surrey Downs rain quantities for all observed rains. This figure shows the much greater variation in

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FIGURE 4-2

RAIN EVENTS-RAIN VOLUMES-RUNOFF VOLUMES

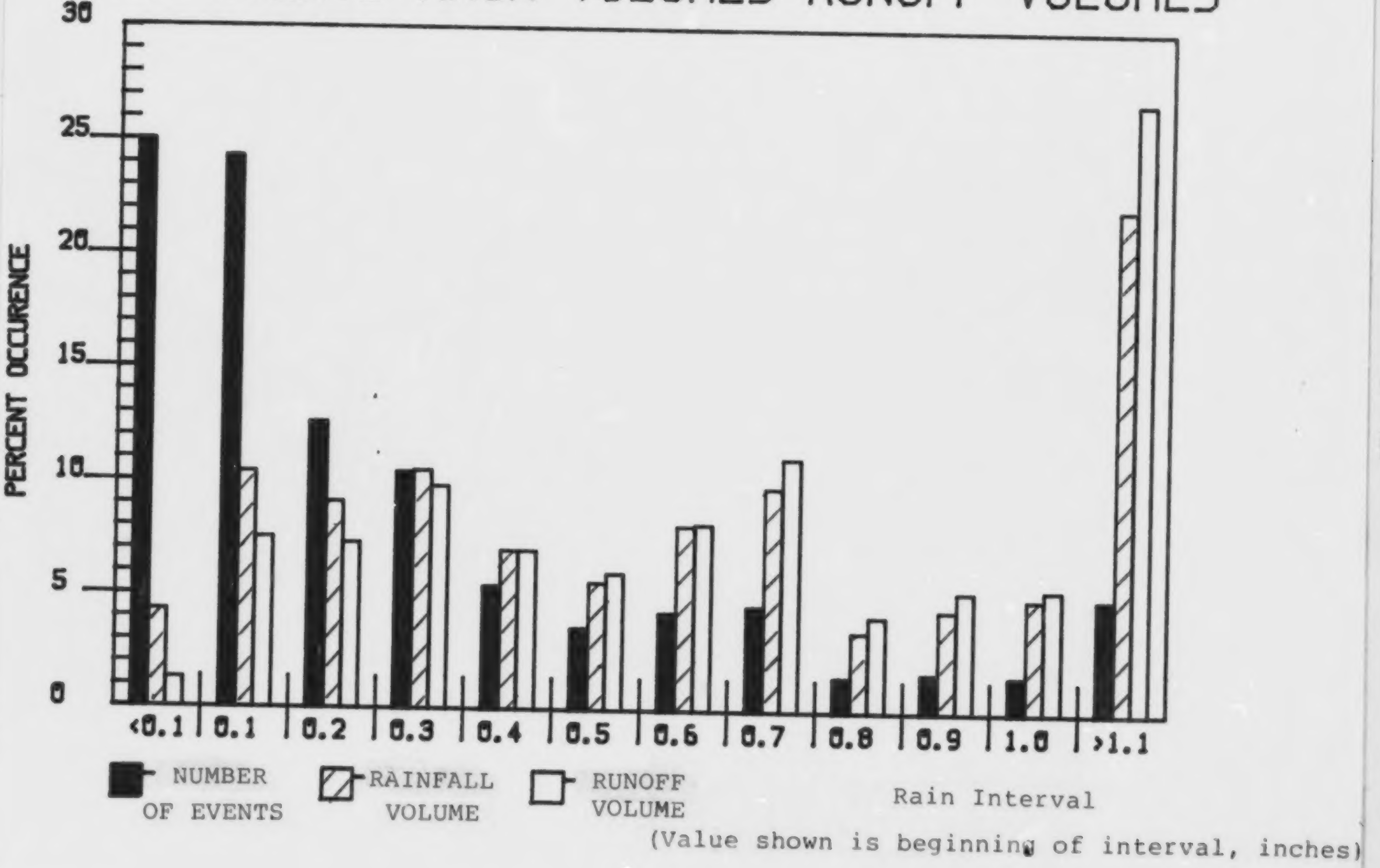

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FIGURE 4-3

LAKE HILLS/SURREY DOWNS WET SEASON RAINS

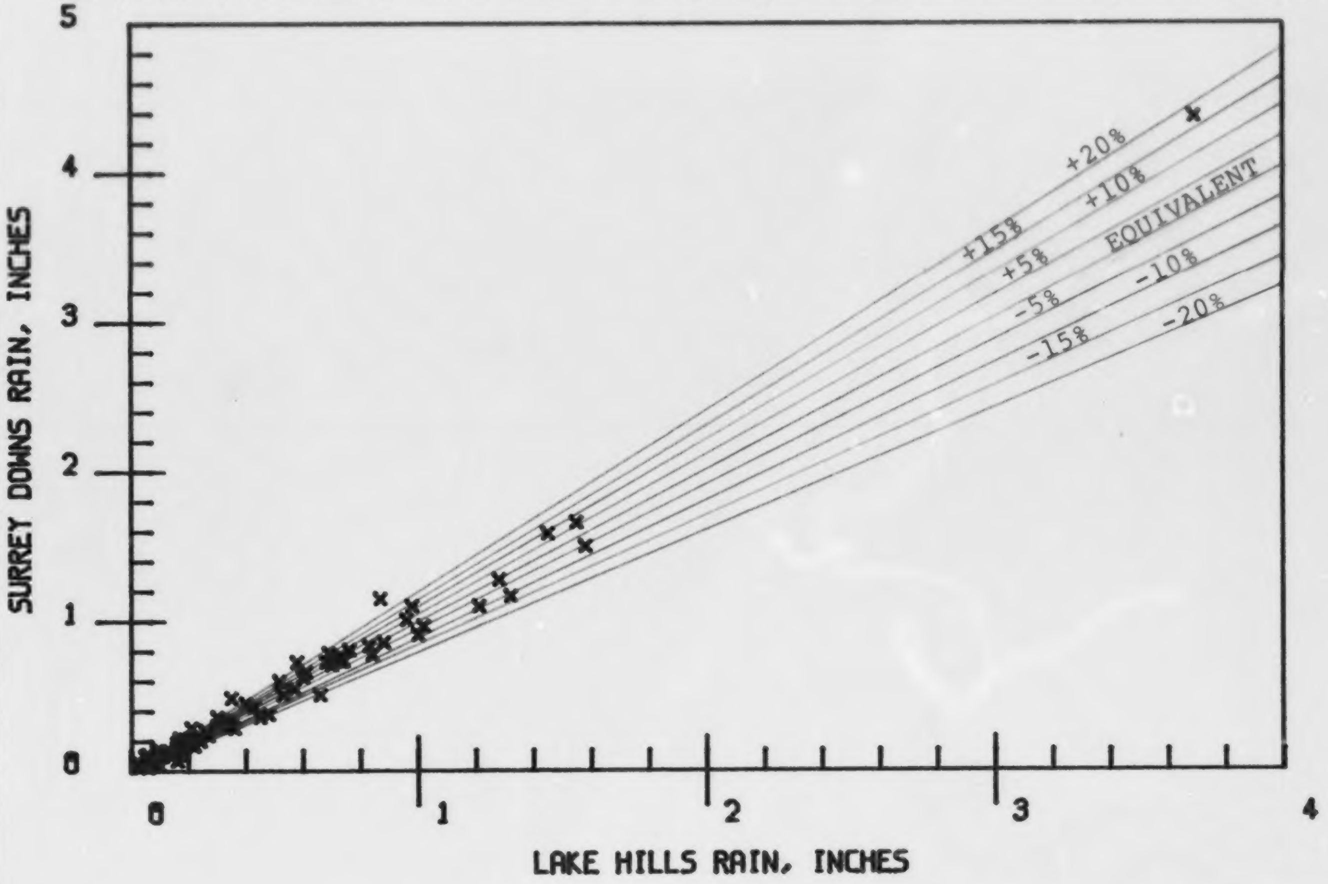

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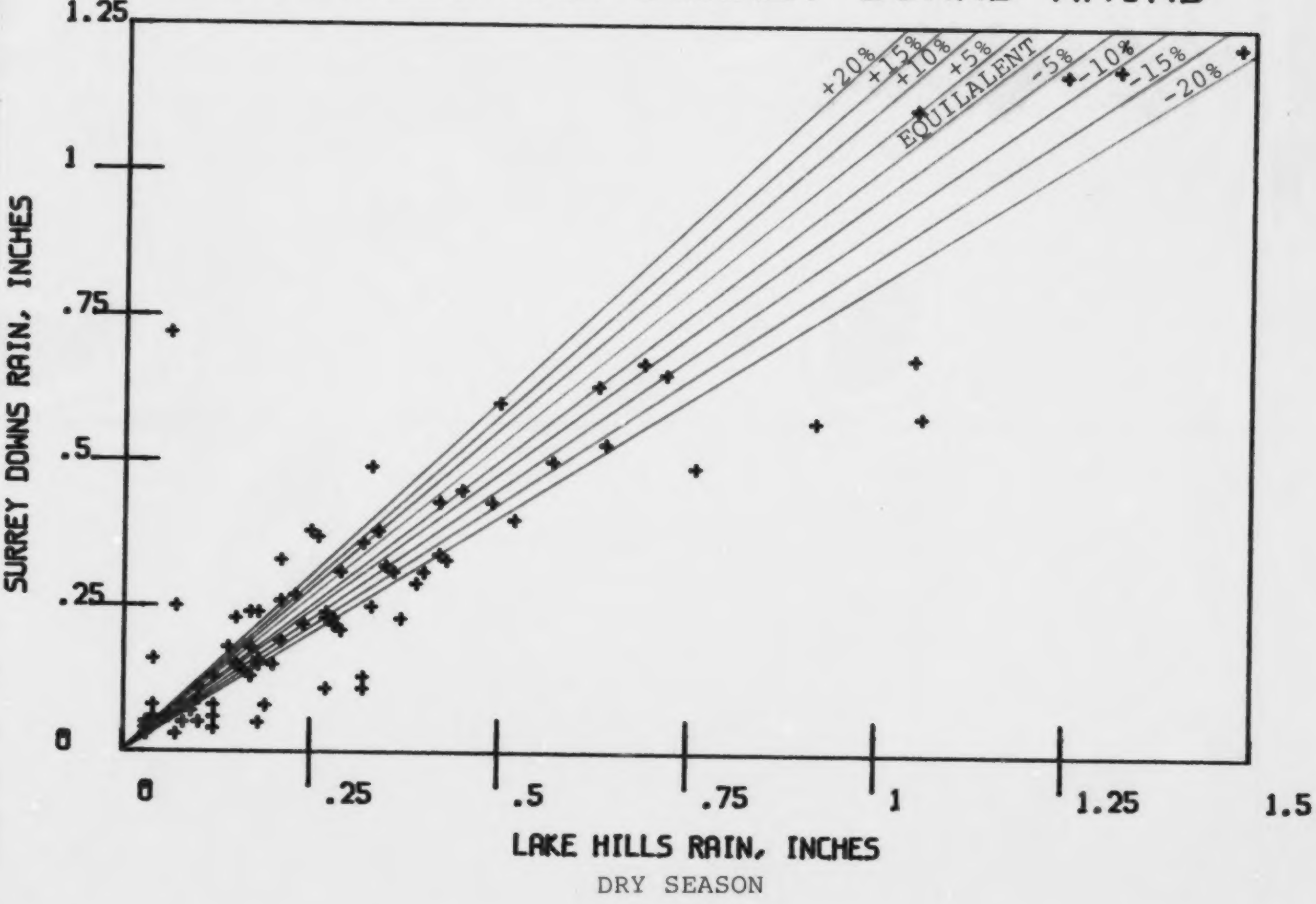
FIGURE 4-4

LAKE HILLS AND SURREY DOWNS RAINS



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observed rain quantities for the smaller rains than for the larger rains. Rains having a total rain quantity of 0.05 inches (1.3 mm) (corresponding to a natural log, or ln, value of about minus three) can have corresponding rains in the other basin ranging from 0.03 to 0.15 inches (0.8 to 3.8 mm). However, rains of 1.5 inches (38 mm) in quantity have a much smaller variation, ranging from about 1.25 to 1.75 inches (32 to 44 mm) in the other basin. The duration variation pattern, as shown on Figure A-8, is similar to the variation pattern shown for total rain quantities. Short duration rains in one basin can occur simultaneously with a wide range of possible duration values in the other basin, while the longer duration rains have more equal values in both basins. Figure A-9 compares the observed peak rain intensities at the two basins. This figure is plotted upside down, with negative natural log values. The data points in the upper right hand corner of the figure correspond to low rain intensities in both basins, while the data points in the lower left hand corner correspond to the higher values. Again, the pattern of variations is similar as for the duration and the quantity plots, in that the small intensities have a much greater variation than the large intensities. All of the intensities vary by much greater values than for the other two rain parameters.

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SECTION 5
RUNOFF QUANTITY

OBSERVED RAINFALL AND RUNOFF VOLUMES

As noted in Section 4, there is a major difference in the production of runoff associated with rains having different volumes. This difference is due to a changing runoff coefficient value for storms of different sizes and for different initial soil moisture conditions. The runoff coefficient monitored in this study was the ratio of runoff volume to total rainfall volume, both being expressed in inches over the test basins. This coefficient (Rv) considers evaporation, transpiration, detention/storage, and soil infiltration. When soil moisture conditions are low and/or if the total rainfall volume is small, then the observed Rv value is small. If the ground is wet at the beginning of the rain and/or if the total rainfall volume is large, then the Rv value is larger. The soil can accept rain that is falling directly on it at a rate equal to its infiltration capacity. If this infiltration capacity is exceeded, the excess rainfall will run off the soil. Therefore, runoff production on pervious surfaces is dependent upon the soil infiltration capacity for the specific soil moisture conditions, vegetation, the rainfall intensity, the rainfall duration, and the total rainfall amount.

When rain falls on an impervious surface, much of the rain will flow off the surface. The heat of the surface will result in some evaporation of the water upon contact with the surface (flash evaporation), but this is more important in areas having very hot days and sudden thunderstorms. Rain may infiltrate through cracks or holes in the otherwise impervious surface and enter the subsoil beneath, or it may be directed off of the impervious surface to pervious areas for infiltration. Also, much concrete is slightly pervious. If the runoff water is directed towards a lined (with impervious materials) channel or to the street and gutter system, it can be called a directly connected impervious area. These areas may include rooftops, sidewalks, and parking areas. Even for these areas, however, some of the rain does not reach the urban runoff system. If the surface is in poor condition, rain can infiltrate through the system, as noted previously; or if the surface is not graded appropriately, water may pond on the surface for future evaporation and "leakage". If the rain is very small, most of the sheet flow could be gone before it has a chance to leave the impervious area. For large rains, however, much more of the rainfall results in runoff from impervious areas.

About 200 rain events were monitored for rainfall quantity and runoff parameters in Surrey Downs and Lake Hills during the two-year study period. Some of the smallest rain events (<0.1 inch or 2.5 mm) were not monitored

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because they did not produce significant runoff. At other times, some rain events were not monitored because of equipment malfunction or because the equipment was being modified and not available. Almost 99 percent of the rain events that occurred at Surrey Downs and about 91 percent of the Lake Hills events were monitored. Tables A-6 and A-7 in Appendix 1 list the rainfall and associated discharge characteristics for each of the monitored rains in both Surrey Downs and Lake Hills. These tables also show the total rain (in inches) and the total discharge (in inches) and calculates the runoff coefficient (Rv) ratio (runoff/rain) for each rain event. The rain durations and the runoff durations are also compared. Typically, the runoff duration can be expected to be greater than the rain duration, depending upon the lag time at the beginning of the rain between the start of rain and the start of runoff. The average rainfall to rain duration ratio in Surrey Downs was 1.14 while this value was 1.24 at Lake Hills. For the smaller rains, this duration ratio was actually less than one because of the proportionately larger amount of infiltration of rain into the soil. The data presented in these two tables are used in this section and elsewhere in this report for rainfall and runoff quantity and quality calculations.

Relationships between runoff volume and rain volume are dependent on many conditions. However, these conditions may be simplified by dividing the study period into appropriate seasons and considering each area separately. The antecedent soil conditions are usually satisfactorily considered in the seasonal breakdown, while the different study areas consider the different land-use configurations. Table 5-1 separates the rainfall and runoff characteristics by season and study area. The total rain volume was slightly greater in the wet season for both areas; there were not as many of the larger rain events during the dry periods of the study, and although there were many more of the smaller rain events, most of the rain quantity occurred during the larger events. During the wet seasons, most of the rainfall volume was associated with rains greater than about 0.4 inches (10 mm). The median rain volumes associated with the runoff were greater than for the rainfall because of the increasing Rv values for increasing rain volumes.

Fiqures A-10 through A-13 in Appendix A show the distribution of these rainfall and runoff parameters for both study areas and wet and dry seasons separately. These are similar to Figure 4-2 in the previous section which combined all of this data. The average Rv value in Lake Hills during the wet season was about 0.3, and about 0.2 during the dry season. The Rv values in Surrey Downs were less.

In order to separate the study period into seasons, characteristics of the rainfall and runoff for each month were examined. Table 5-2 shows equation coefficients corresponding to straight-line relationships between rainfall and runoff (both expressed in inches). The resultant r^2 values (which is an indication of how well the calculated curve fits the data points) were very good. In most cases, the r^2 value was greater than 0.95 with a value of 1.0 being a perfect fit. These equations are only good for the larger rains and do not produce appropriate values for rains that are smaller than about 0.1 inches (2.5 mm). (The predicted runoff volumes were negative for these smaller rains). The observed runoff volumes for the small rains were very small, but could obviously not be negative. The bottom of

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Table 5-1. RAIN AND RUNOFF VOLUMES

	Number of events	Median rain volume (in.)	Total rain during study (in.)	Total runoff during study (in.)	Overall Rv
Lake Hills					
wet	113	0.23	44.96	14.36	0.32
dry	107	0.17	30.55	6.08	0.20
total	220	0.20	75.51	20.44	0.27
Surrey Downs					
wet	98	0.23	42.79	10.56	0.25
dry	102	0.20	28.15	4.91	0.17
total	200	0.21	70.91	15.47	0.22
All Combined	420	0.21	146.42	35.91	0.25

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Table 5-2. STRAIGHT-LINE EQUATION COEFFICIENTS TO PREDICT RUNOFF FROM RAIN VOLUMES (FOR RAINS GREATER THAN THE MINIMUM VALVES SHOWN)(1)

	Lake Hills					Surrey Downs				
Month	intercept	slope	R^2	N	Min. Value (rain)	intercept	slope	R^2	N	Min. Value
January	-0.017	0.41	0.93	20	0.07	-0.0047	0.26	0.98	19	0.09
February	-0.0028	0.29	0.94	12	0.16	-0.0080	0.35	0.79	6	0.16
March	-0.048	0.40	0.96	9	0.19	-0.010	0.25	0.93	20	0.11
April	-0.020	0.30	0.98	21	0.18	-0.014	0.21	0.95	21	0.11
May	-0.011	0.21	0.95	16	0.10	-0.011	0.23	0.97	17	0.14
June	-0.0090	0.22	0.96	21	0.08	-0.011	0.20	0.94	17	0.11
July	-0.031	0.30	0.98	6	0.15	-0.0096	0.19	0.99	7	0.15
August	-0.013	0.26	0.95	8	0.08	-0.0056	0.17	0.94	7	0.08
September	-0.024	0.30	0.96	16	0.12	-0.012	0.20	0.98	4	0.14
October	-0.046	0.39	0.99	11	0.16	-0.026	0.29	0.99	13	0.16
November	-0.018	0.39	0.98	30	0.09	-0.0017	0.24	0.98	25	0.05
December	-0.029	0.45	0.97	31	0.16	-0.0098	0.31	0.95	31	0.08
Total Wet	-0.020	0.39	0.96	99	0.10	-0.0077	0.28	0.96	94	0.07
Total Dry	-0.023	0.30	0.95	97	0.12	-0.010	0.21	0.93	98	0.11

Rain (inches)	Lake Hills				Surrey Downs			
	wet		dry		wet		dry	
	calc. Runoff	calc Rv	calc. Runoff	calc. Rv	calc. Runoff	calc. Rv	calc. Runoff	calc. Rv
0.01	-0.016	----	-0.020	----	-0.0049	----	-0.0079	----
0.1	0.019	0.19	0.007	0.07	0.020	0.20	0.011	0.11
0.2	0.058	0.29	0.037	0.19	0.048	0.24	0.032	0.16
0.4	0.14	0.34	0.097	0.24	0.10	0.26	0.074	0.19
0.8	0.29	0.37	0.22	0.27	0.22	0.27	0.16	0.20
1.6	0.60	0.38	0.46	0.29	0.44	0.28	0.33	0.20
2.5	0.96	0.38	0.73	0.29	0.69	0.28	0.52	0.21

(1) runoff = intercept + slope (rainfall)
example for 0.5 inch rain in Lake Hills during April:
runoff = -0.02 + 0.03 (0.5) = 0.13 inches
and the Rv = $^{\text{runoff}}/_{\text{rain}}$ = $^{0.13}/_{0.5}$ = 0.26

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Table 5-2 shows how the Rv value increases with increasing rain volumes. This table also shows that the wet season Rv values can be as much as two times the dry season Rv values for rains smaller than about 0.25 inches (6.4 mm). The Lake Hills site also had generally larger Rv values than the Surrey Downs site for rains greater than 0.1 inch (2.5 mm).

Figures 5-1 through 5-4 are plots of observed rainfall versus runoff volumes for both Lake Hills and Surrey Downs and separated for dry and wet seasons. These figures show how the smaller rain events have very low Rv values, which then increase with the size of rain. The variations in observed runoff for the smaller rains were quite large. This percentage error decreases as the rain volume increases. The wet seasons included a single rainstorm that was about twice as large as the next largest rain. This very large rain event (about four inches, or 100 mm) accounted for much of the total annual runoff. That single event rain volume is infrequent in Bellevue, with a return interval of once every several years. Even for this large rain, the resultant Rv value was only about 0.4 in Lake Hills and about 0.3 in Surrey Downs.

A detailed analysis of rain and runoff characteristics was carried out for most of the Lake Hills data. A multiple regression analysis relating Rv to total rain, average rain intensity, peak rain intensity, and days since last rain was made for each month. These analyses showed that the rainfall volume alone accounted for about 95 percent of the calculated Rv value. The peak rain intensity values accounted for between five and ten percent of the total Rv value. Increases in Rv values were caused by increases in peak intensity values. As the number of days since the last rain increased, the Rv value decreased. This antecedent factor can reduce the Rv value by about five percent. These decreases in Rv with increase in antecedent dry periods was probably due to the soils drying. It was found that average rain intensities affected the Rv values by less than about five percent. The season of the year was extremely important in determining the runoff and rainfall relationships. The Rv values for the winter (wet) months of November through February were about 35 percent larger than the Rv values for the drier summer months of March through October for the same rain characteristics. It was concluded that there is no real need to adjust the calculated Rv values based on rain intensity or preceding length of dry period: it is only necessary to consider total rainfall and season.

THE EFFECTS OF LAND-USE ON RUNOFF QUANTITY

A runoff model specific for Surrey Downs and Lake Hills was constructed. This model considered the specific land covers in each of the two basins and the distribution of observed rains during the two year period of study. Table 3-1 in Section 3 listed the land covers in the Surrey Downs and Lake Hills basins. This breakdown includes the percentage of the area and the total square footage for vacant land, parks, back yards, front yards, rooftops, driveways, parking lots, and streets. The resultant impervious and pervious fractions were also calculated. It is important to separate the pervious areas into these several classifications. These classifications are mostly based upon their distance from the drainage system, size, and the amount of

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FIGURE 5-1

LAKE HILLS DRY SEASON RAIN/RUNOFF

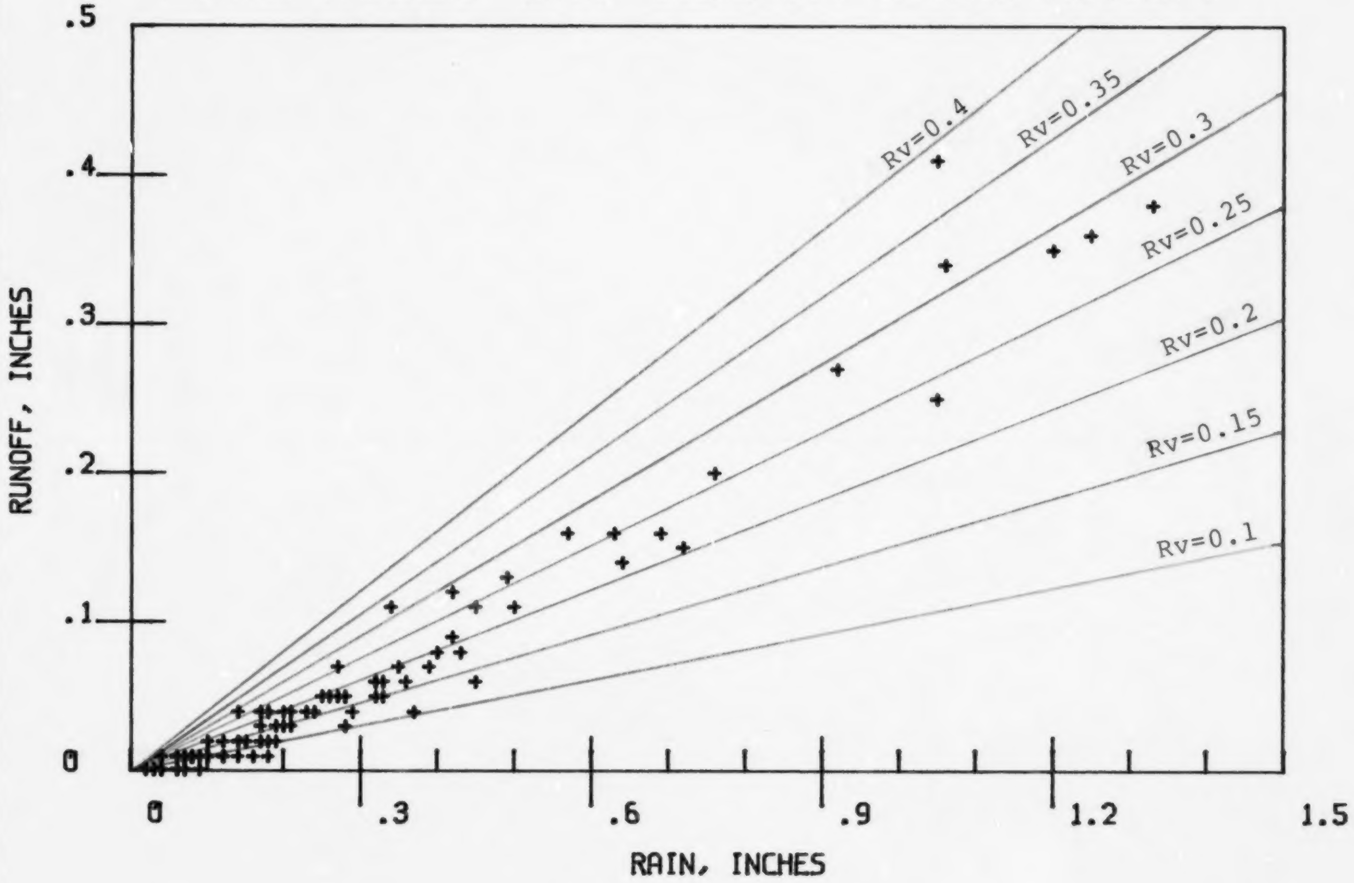

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FIGURE 5-2

SURREY DOWNS DRY SEASON

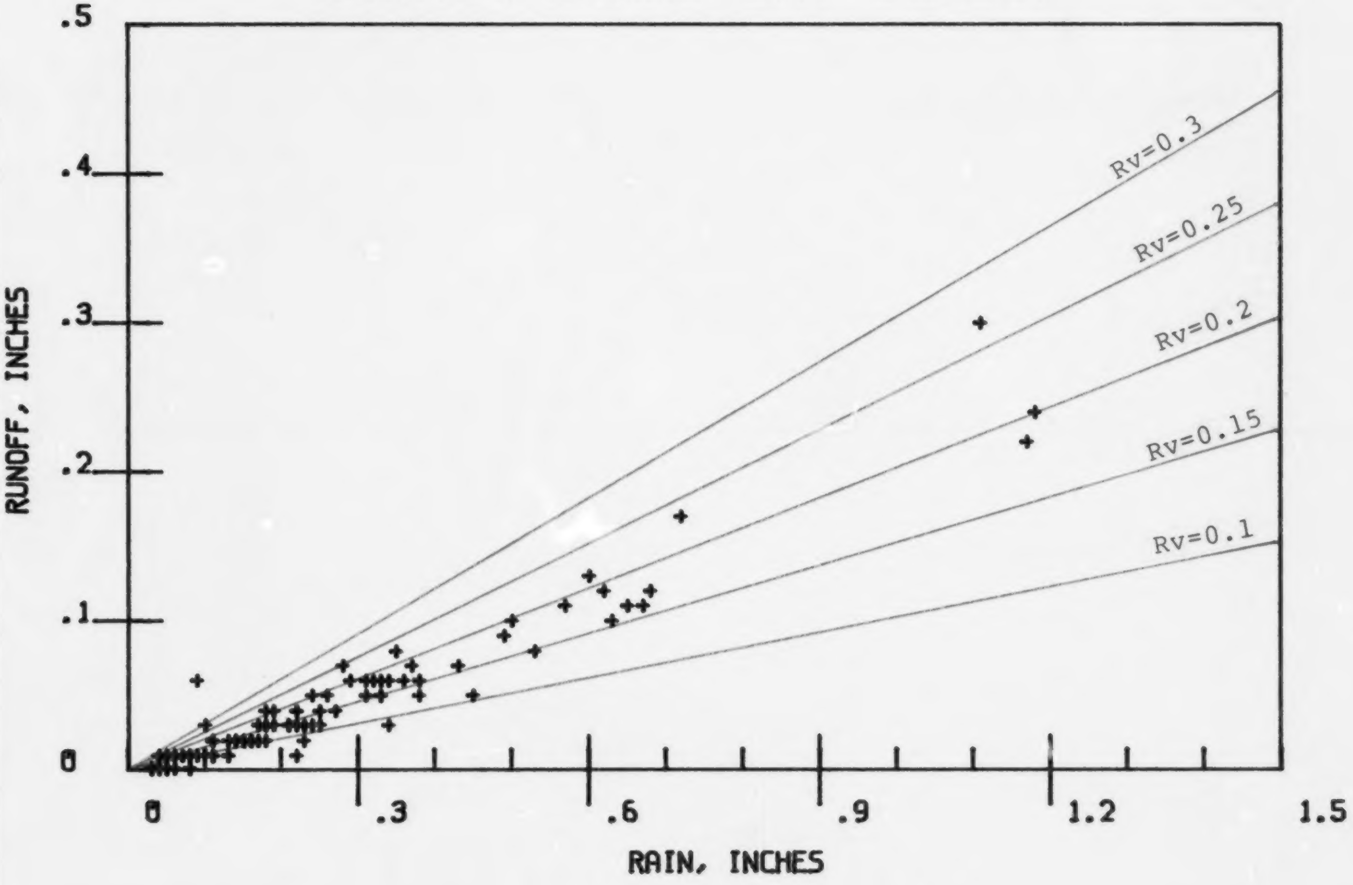

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FIGURE 5-3

LAKE HILLS WET SEASON RAIN/RUNOFF

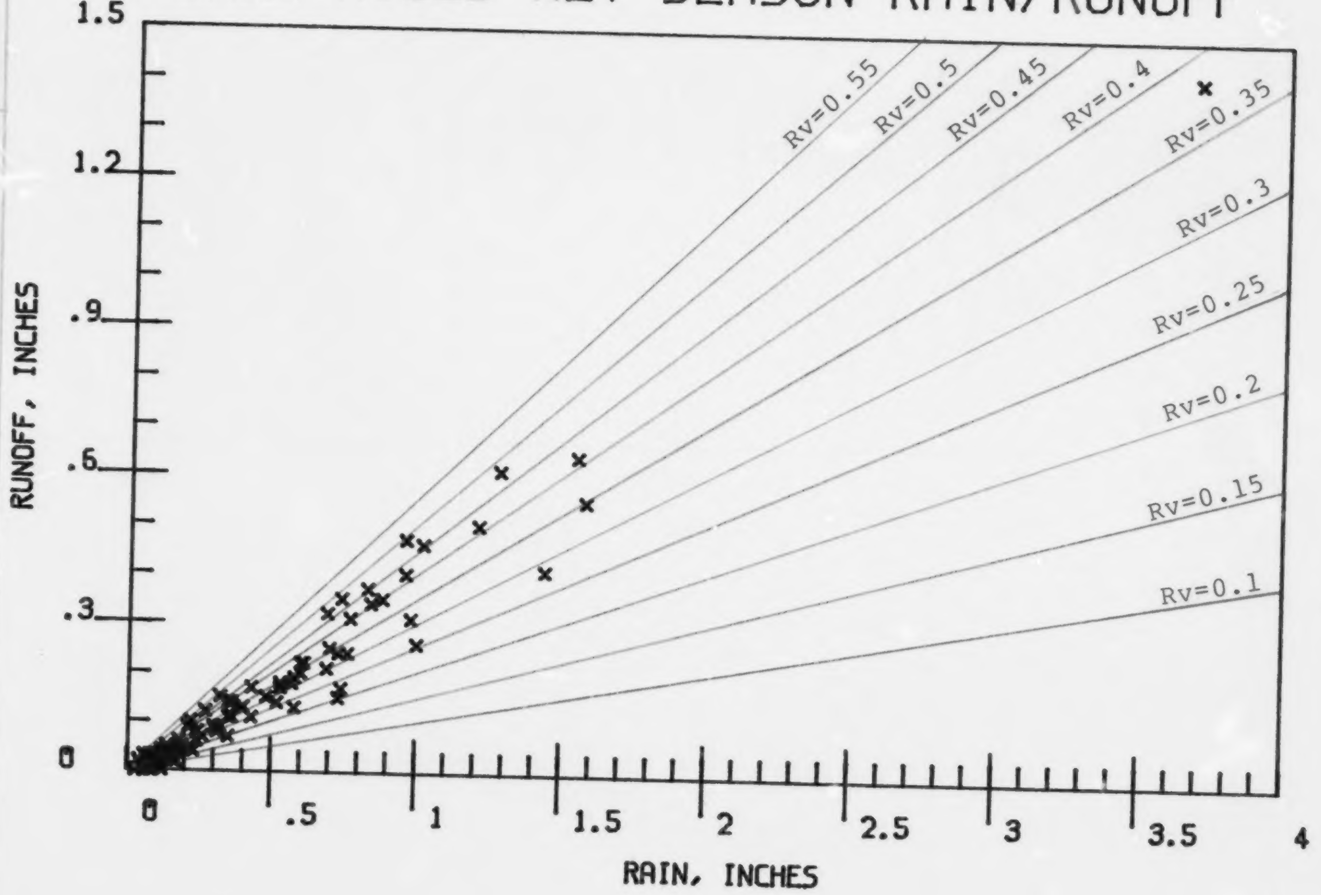

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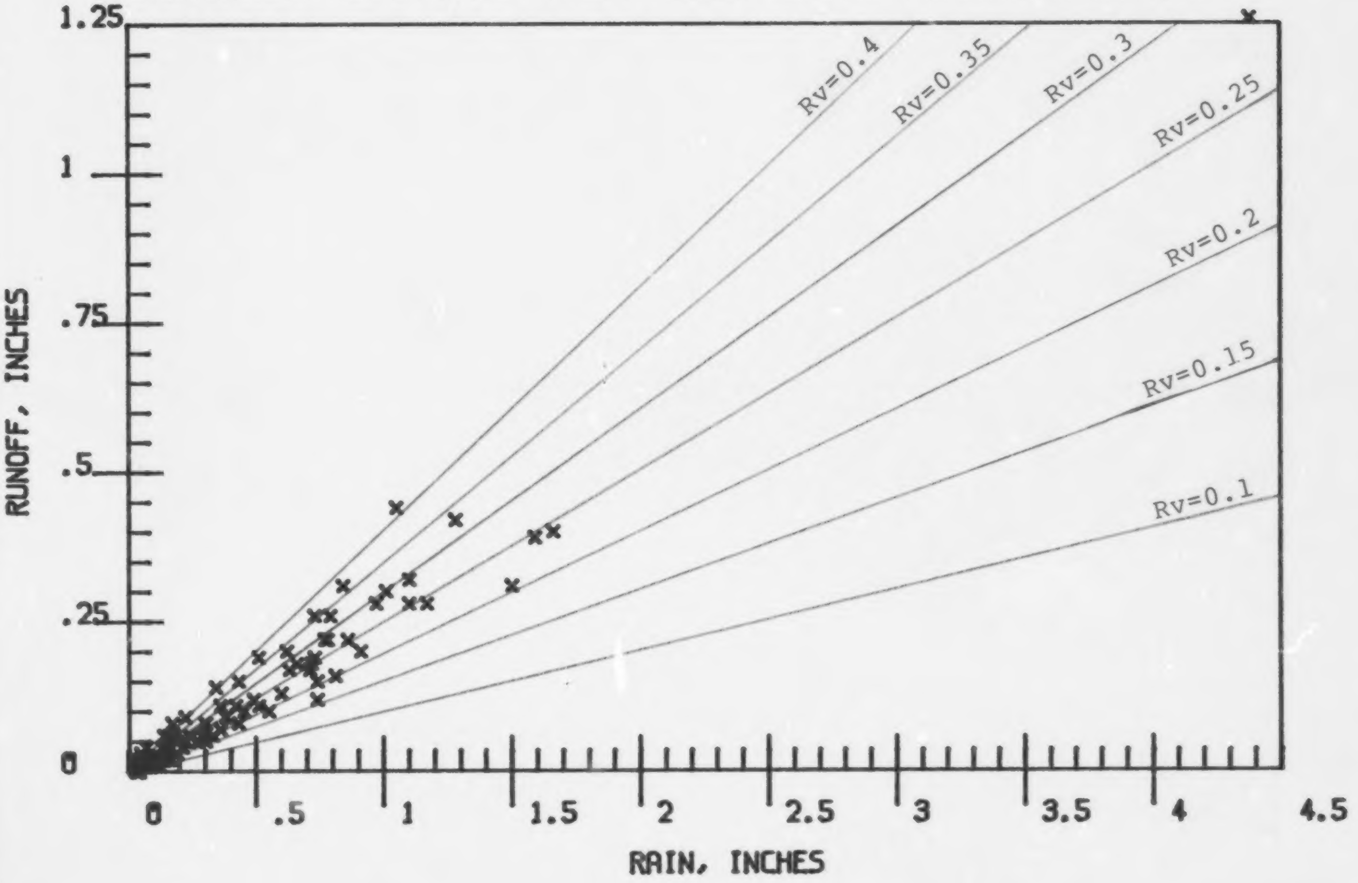
FIGURE 5-4

SURREY DOWNS WET SEASON RAIN/RUNOFF



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surface disruption. For those areas that are far from the drainage area, much of the rainfall could infiltrate before reaching the drainage system. Large pervious areas, such as vacant lots and parks, may have more infiltration than front yards that are located adjacent to the drainage system. Rooftops, even though they are usually considered impervious, have most of their downspouts in these two basins directed towards the surrounding back or front yards. This allowed much of the rooftop runoff to infiltrate into the soils around the house. A portion of the driveways and parking lots are also directed towards surrounding pervious areas. However, all of the street surfaces are directly connected to the drainage system.

As previously discussed, the overall Rv value for the drainage basins were very small for small rains, but then increased rapidly to a fairly constant value for the larger rains. When this is considered in conjunction with the runoff characteristics from the different land covers, the amount of runoff originating from each of the land-use covers in the test basins can be determined for each type of rain. This is very important when considering the effectiveness of various control measures. If a control measure can thoroughly clean a sub-area in the drainage basin, the observed effect on the overall basin runoff quality is highly dependent upon the runoff and associated pollutant contributions from that sub-area. This discussion will consider the runoff quantity that originates from each of these land covers for different rain types, study basins, and seasons of the year. Section 6 will discuss runoff quality and estimate the runoff pollutant contributions from each of these land-use covers.

Table 5-3 shows how the composite Rv value is made up of different land-use configuration runoff coefficients (k). These individual land-use coefficients are multiplied by the fraction of the total area that each of these land covers occupy (as shown previously in Table 3-1). These individual land cover runoff coefficients all increase with increasing rain volumes and as the distance to the drainage system decreases. These runoff coefficient values are much greater for the impervious areas than for the pervious areas for the same rains. For very small rains, no runoff is expected to occur from the pervious areas and from the impervious areas that drain to these pervious areas. Starting at about 0.1 inch (2.5 mm), however, the coefficients are about 0.3 to 0.5 times the maximum values that they are likely to have. The dry season runoff coefficient values are less than the wet season values, due to lower soil moisture conditions.

The runoff coefficient values for the impervious areas are lower than most people would expect, especially for the smaller rain events. Especially during the dry summer season, rainfall falling on these impervious areas can be flash evaporated and/or ponded for future evaporation. These two factors are extremely important for the smaller rain events. Even for the largest rain events, the impervious component runoff coefficient values may be as low as 0.6 for the dry season and 0.7 for the wet season. Runoff coefficient values for paved areas are usually expected to range from about 0.7 to 0.95. Values within this range are expected for large rains. Runoff coefficient values that are usually used in runoff modeling are also shown on this table. These values from Claycomb, 1970, are usually within the values found for the pervious areas and for moderate to large rain events. When a storm drainage

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Table 5-3. RUNOFF COEFFICIENT RELATIONSHIPS

SURREY DOWNS - DRY SEASON

k values for each land cover and rain total (inches)

	Rainfall (inches)							Literature values
Land Cover	0.01	0.1	0.2	0.4	0.8	1.6	2.5	(Claycomb, 1970)
Vacant	0	0.05	0.05	0.05	0.05	0.05	0.1	0.1 to 0.2
Parks	0	0.05	0.05	0.05	0.05	0.05	0.1	0.1 to 0.2
Backyard	0	0.05	0.05	0.05	0.05	0.05	0.1	0.1 to 0.2
Frontyards	0	0.05	0.1	0.15	0.15	0.15	0.2	0.1 to 0.2
Rooftops	0	0.1	0.15	0.15	0.15	0.15	0.2	0.75 to 0.95
Driveways	0.1	0.2	0.3	0.6	0.6	0.6	0.6	0.75 to 0.85
Parking Lots	0.1	0.2	0.3	0.6	0.6	0.6	0.6	0.7 to 0.95
Streets	0.1	0.35	0.5	0.6	0.6	0.6	0.6	0.7 to 0.95
Composite Rv value:	0.02	0.10	0.15	0.20	0.20	0.20	0.24	
SCS (1975) values:	too small for SCS method				0.1	0.3	0.4	

LAKE HILLS - DRY SEASON

k values for each land cover and rain total (inches)

	Rainfall (inches)							Literature values
Land Cover	0.01	0.1	0.2	0.4	0.8	1.6	2.5	(Claycomb, 1970)
Vacant	0	0.05	0.05	0.05	0.05	0.05	0.1	0.1 to 0.2
Parks	0	0.05	0.05	0.05	0.05	0.05	0.1	0.1 to 0.2
Backyard	0	0.05	0.05	0.05	0.1	0.1	0.15	0.1 to 0.2
Frontyards	0	0.05	0.1	0.15	0.15	0.2	0.3	0.1 to 0.2
Rooftops	0	0.1	0.15	0.25	0.3	0.4	0.4	0.75 to 0.95
Driveways	0.1	0.2	0.3	0.4	0.65	0.7	0.7	0.75 to 0.85
Parking Lots	0.1	0.2	0.3	0.4	0.65	0.7	0.7	0.7 to 0.95
Streets	0.1	0.35	0.5	0.6	0.7	0.75	0.8	0.7 to 0.95
Composite Rv value:	0.02	0.10	0.15	0.20	0.25	0.29	0.34	
SCS (1975) values:	too small for SCS method				0.1	0.3	0.4	

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Table 5-3. RUNOFF COEFFICIENT RELATIONSHIPS (cont.)

SURREY DOWNS - WET SEASON

k values for each land cover and rain total (inches)

	Rainfall (inches)							Literature values
Land Cover	0.01	0.1	0.2	0.4	0.8	1.6	2.5	(Claycomb, 1970)
Vacant	0	0.05	0.05	0.05	0.1	0.1	0.15	0.1 to 0.2
Parks	0	0.05	0.05	0.05	0.1	0.1	0.15	0.1 to 0.2
Backyard	0	0.1	0.1	0.1	0.1	0.1	0.15	0.1 to 0.2
Frontyards	0	0.15	0.2	0.2	0.2	0.2	0.2	0.1 to 0.2
Rooftops	0	0.2	0.2	0.2	0.2	0.25	0.3	0.75 to 0.95
Driveways	0.1	0.4	0.5	0.6	0.6	0.6	0.6	0.75 to 0.85
Parking Lots	0.1	0.4	0.5	0.6	0.65	0.7	0.7	0.7 to 0.95
Streets	0.1	0.5	0.6	0.63	0.67	0.7	0.7	0.7 to 0.95
Composite Rv value:	0.02	0.20	0.23	0.24	0.25	0.26	0.29	
SCS (1975) values:	too small for SCS method				0.1	0.3	0.4	

LAKE HILLS - WET SEASON

k values for each land cover and rain total (inches)

	Rainfall (inches)							Literature values
Land Cover	0.01	0.1	0.2	0.4	0.8	1.6	2.5	(Claycomb, 1970)
Vacant	0	0.05	0.05	0.1	0.1	0.1	0.15	0.1 to 0.2
Parks	0	0.05	0.05	0.1	0.1	0.1	0.15	0.1 to 0.2
Backyard	0	0.1	0.17	0.18	0.18	0.2	0.2	0.1 to 0.2
Frontyards	0	0.15	0.22	0.28	0.3	0.3	0.35	0.1 to 0.2
Rooftops	0	0.2	0.25	0.33	0.38	0.4	0.5	0.75 to 0.95
Driveways	0.1	0.4	0.5	0.6	0.7	0.75	0.8	0.75 to 0.85
Parking Lots	0.1	0.4	0.5	0.65	0.75	0.8	0.9	0.7 to 0.95
Streets	0.1	0.5	0.6	0.67	0.75	0.8	0.9	0.7 to 0.95
Composite Rv value:	0.02	0.20	0.26	0.31	0.34	0.36	0.40	
SCS (1975) values:	too small for SCS method				0.1	0.3	0.4	

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system is designed, the design storm is a large storm in order to reduce the flooding potential in the drainage basin. Very little research has been directed towards the much more numerous smaller events.

These component runoff coefficient values were estimated based upon the monitored composite Rv values, the rain totals, and the land cover configurations. A trial and error procedure was used to fit the corresponding runoff coefficient values. Data from other locations and other land-use types were also used in this analysis (especially Ottawa, Ontario; Pitt, 1982, and Castro Valley, California; Pitt and Shawley, 1981). Unfortunately, the Surrey Downs and Lake Hills sites were quite similar. When the Bellevue 148th Avenue runoff/rainfall information becomes available from the USGS, then these runoff coefficients can be confirmed for a different local land-use.

The calculated composite Rv values are within ten percent of the observed values. They are also compared to values obtained using the SCS (1975) curve number method on Table 5-3. The SCS method was also developed for the larger storm events and is not useful for those rains smaller than about one inch (25 mm). Unfortunately, almost all of the Bellevue rains are smaller than one inch (25 mm). However, the SCS calculated Rv values were high in all categories, except for the very largest rain events during the Lake Hills wet season. There are modifications that can be made to these initial SCS estimates that consider antecedent dry periods and more specific soil information.

The portion of the total urban runoff flow (as measured at the outfall) that originates from each of the land covers within the basin can be calculated. Each individual runoff coefficient value (as shown in Table 5-3) can be multiplied by the corresponding land cover fractions (from Table 3-1) to obtain the relative contribution of runoff that originates from each of those land covers for different rains. Figures 5-5 through 5-8 show these calculated estimates for different seasons and different size rain events. Street surfaces are seen to contribute most of the urban runoff flows only for the very smallest rain events (less than about 0.03 inch, or 0.8 mm, of rain). The contributions of street surface flows to Lake Hills urban runoff flows is greater than for Surrey Downs. For rains greater than about 0.1 inch (2.5 mm), the contributions of street surface flow to the urban runoff yield is estimated to be about 25 percent for both basins during the dry season. These percentage contributions may decrease even more for the very large events when more runoff comes from the pervious areas. For the very smallest events, the only land covers that contribute any runoff at all are the street surfaces, driveways, and parking lots. The rooftops and pervious areas start to contribute runoff in important quantities after about 0.1 inch (2.5 mm) of rain. When driveways and parking lots are added to the street surfaces, these areas can contribute more than 50 percent of the runoff in Surrey Downs and more than about 40 percent in Lake Hills for most rains. Because of the small number of vacant lots and parks in these basins, runoff in these areas typically contribute only a few percent of the total runoff reaching the outfall.

The resultant hydrograph from a typical urban basin is made up of various components from each of the land cover areas. Figure 5-9 shows how

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FIGURE 5-5

RUNOFF SOURCES Surrey Downs - Wet Season

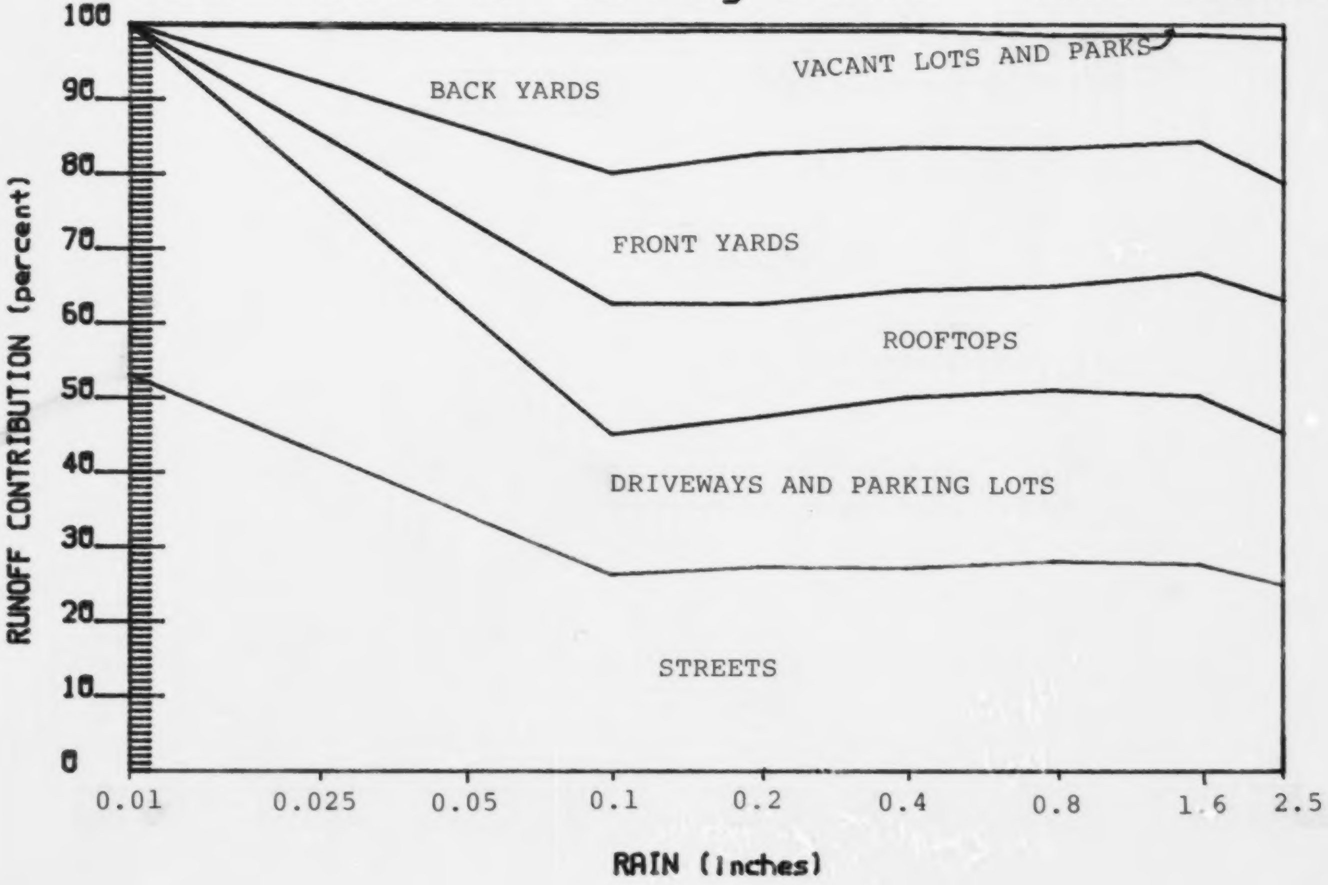

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FIGURE 5-6

RUNOFF SOURCES Lake Hills - Wet Season

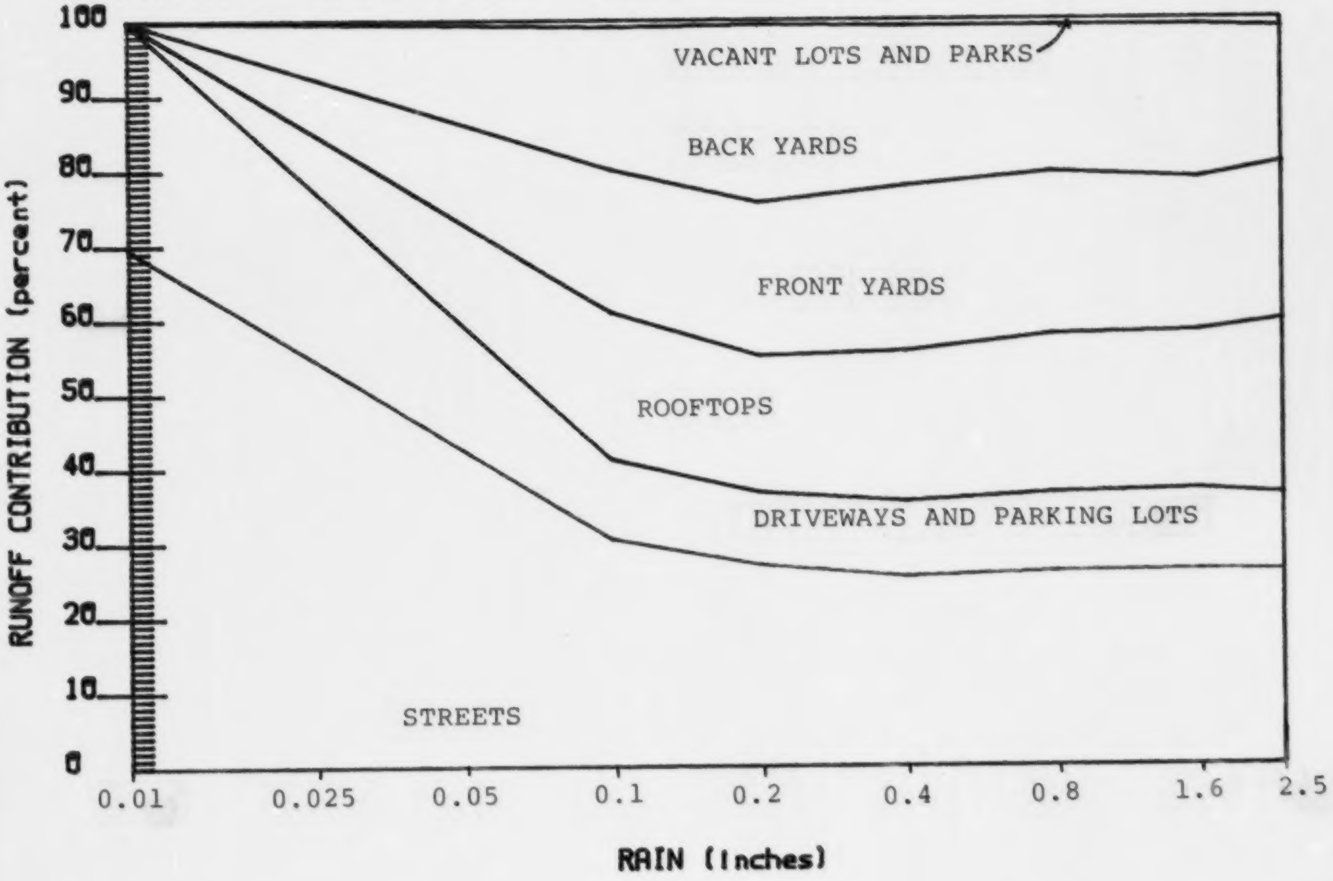

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FIGURE 5-7

RUNOFF SOURCES Surrey Downs - Dry Season

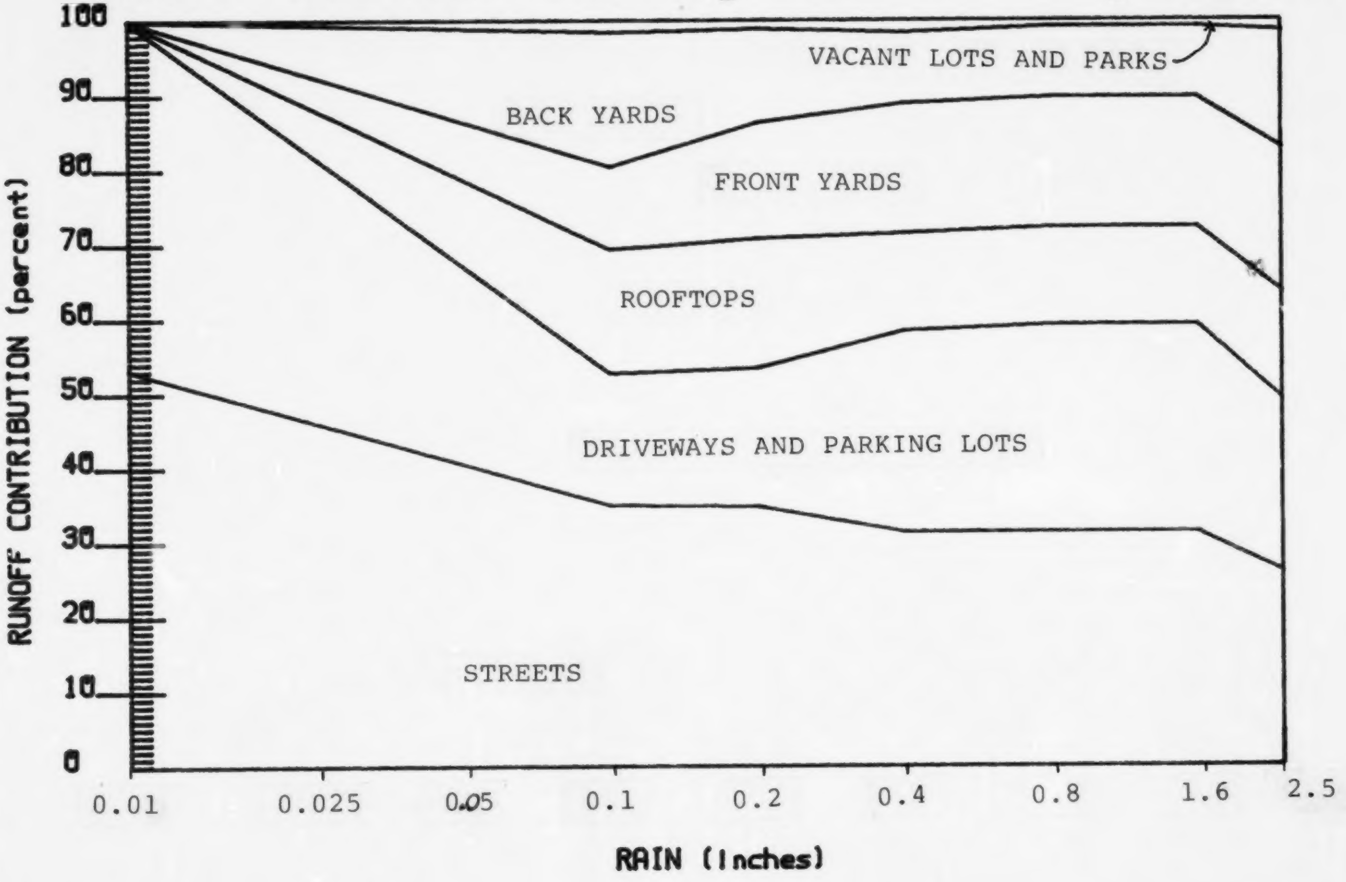

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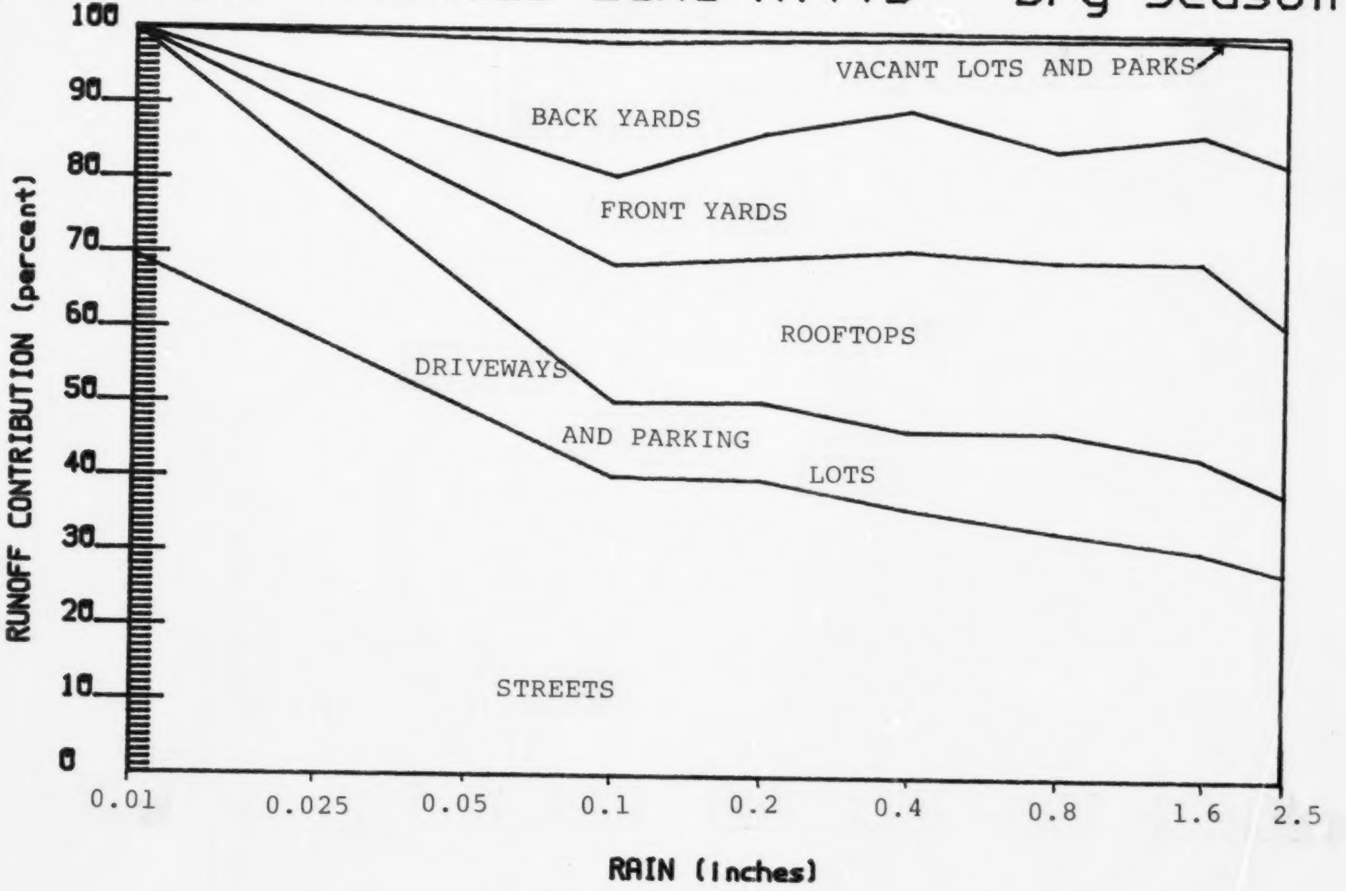
FIGURE 5-8

RUNOFF SOURCES Lake Hills - Dry Season



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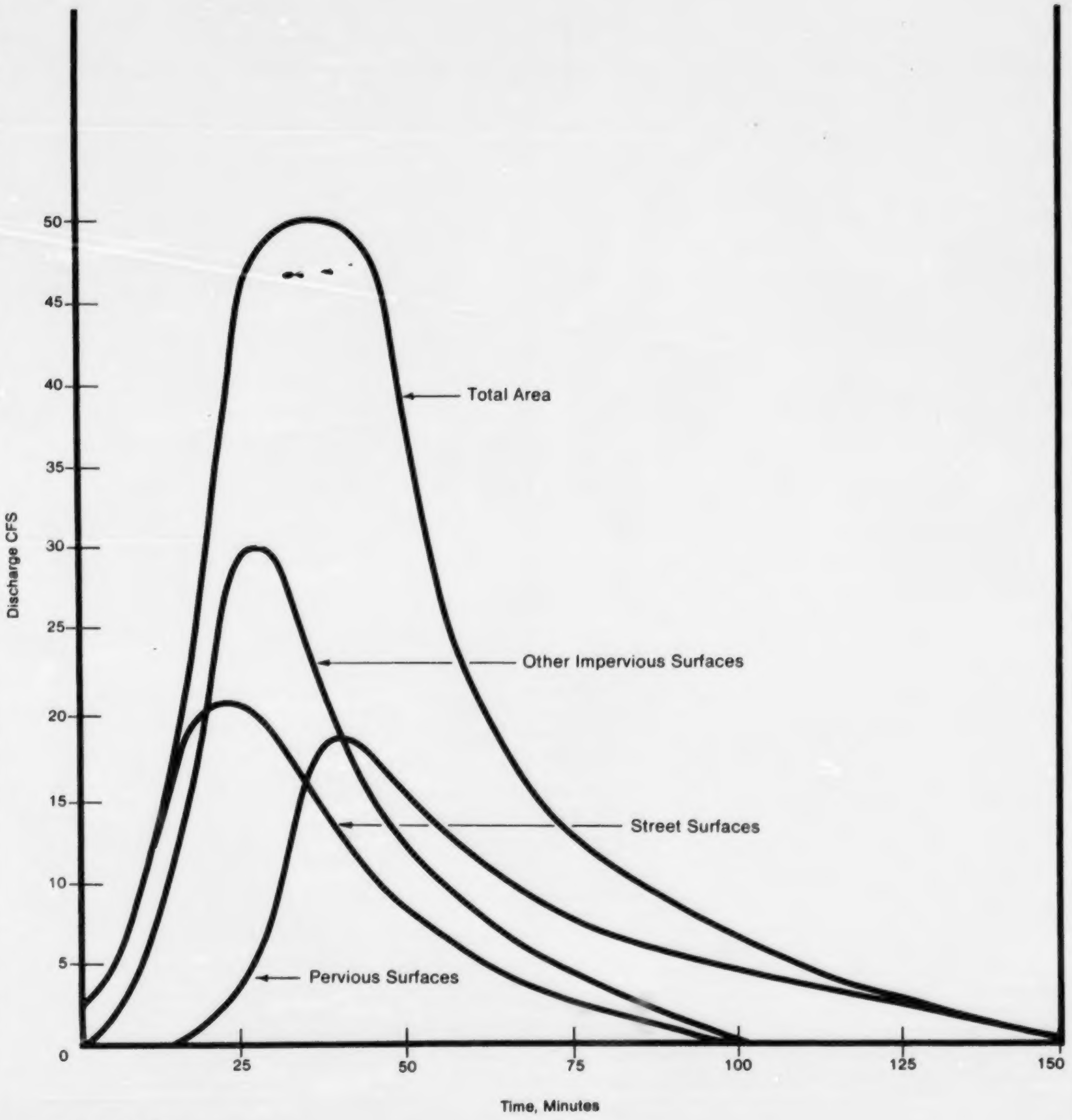

FIGURE 5-9 Hypothetical Hydrograph for Urban Watersheds

Source: from Amy, Pitt, Singh, Bradford and La Graff, 1974.

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the initial flows during an urban runoff event will originate mostly from street surfaces. Other impervious areas located further from the drainage system start contributing flows at later times and finally, after the ground becomes saturated and if the rain lasts for a long enough period of time, pervious surfaces start contributing flows. Flows from the directly connected impervious areas (street surfaces and some sidewalk or parking lots and possibly rooftops) stop soon after the rainfall stops. The runoff from the pervious areas, however, may continue long after the rainfall has stopped. Therefore, even though street surfaces contribute a small fraction of the total runoff volume for the larger rain events, they contribute most of the flows at the beginning of the events. Small rain events in Bellevue are much more common than large rain events. Therefore, street cleaning may have a much greater effect throughout the year because of the number of small events than if only the total mass flow is considered which stresses the larger events.

SEASONAL TRENDS IN RUNOFF AND BASEFLOW QUANTITY

The distribution of total flows throughout the study period are shown in Figures 5-10 and 5-11. These figures dramatically point out the seasonal aspects of urban runoff in Bellevue. The variation by season in urban runoff flow is much greater than the variation in the number of rain events or the total rainfall volume. These figures also show the baseflow contributions that were observed during the study period. These trends are important when considering the period of time that the small rain events are most influential and during which street cleaning may be most effective. It is obvious that street cleaning would have very little effect during periods of very large flows (from September or October through December). Street cleaning may be most effective during the drier months, especially form April or May through July.

Figures 5-12 and 5-13 show the distribution of base flows and runoff flows by month for Lake Hills. Similar figures for Surrey Downs are Figures A-14 and A-15 in Appendix A. These figures dramatically show that the winter months contribute most of the urban runoff flows. Average October, November, and December flows for the study period contributed about half of the total annual runoff flows observed. December through March contributed more than half of the base flows. Generally, the base flows were highest in those months also having high storm runoff flows. About 2.6 million cubic feet (74 million liters) of storm runoff and about 780,000 cubic feet (22 million liters) of base flow per year were monitored in Surrey Downs. The storm runoff flows in Lake Hills were greater, being about 4.2 million cubic feet (120 million liters) while the base flows were less, at about 500,000 cubic feet (14 million liters) per year. August was the driest month, with less than two percent of the annual urban runoff flow. Table 5-4 shows the actual monitored base and urban runoff flows that occurred in both of the study areas during each month of the study.

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FIGURE 5-10

LAKE HILLS TOTAL FLOWS BY MONTH

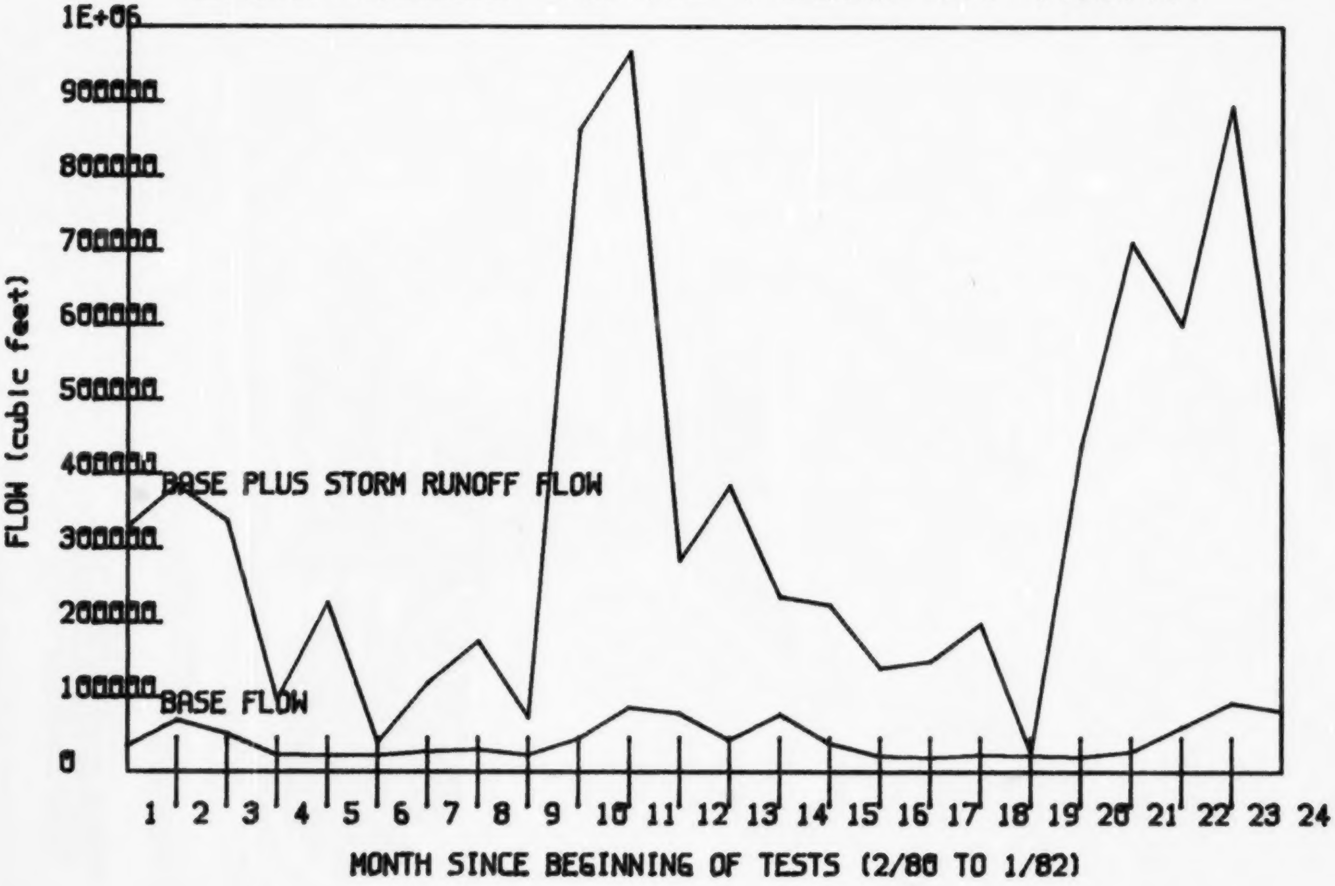

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FIGURE 5-11

SURREY DOWNS TOTAL FLOWS BY MONTH

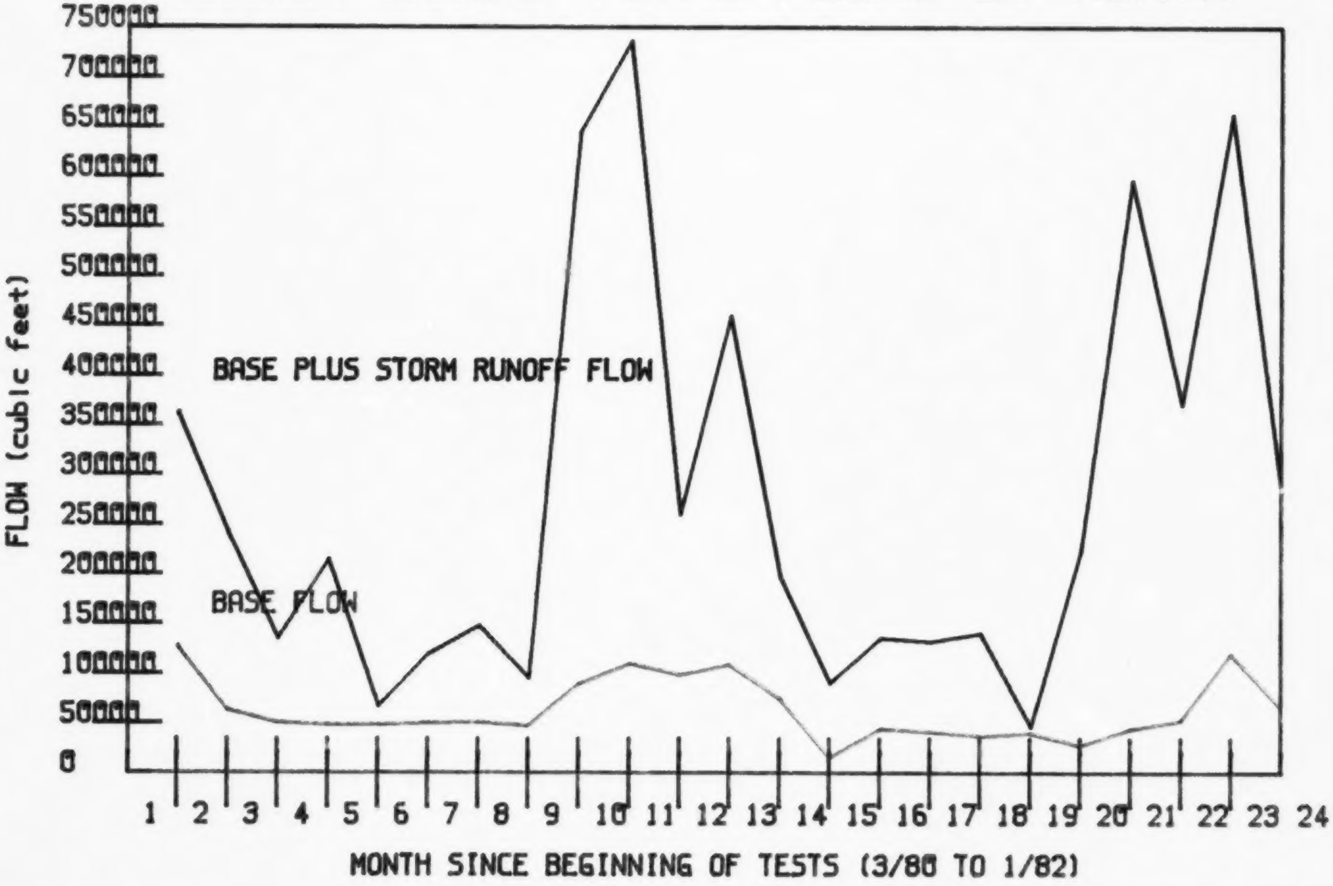

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FIGURE 5-12

LAKE HILLS BASE FLOW (percent by month)

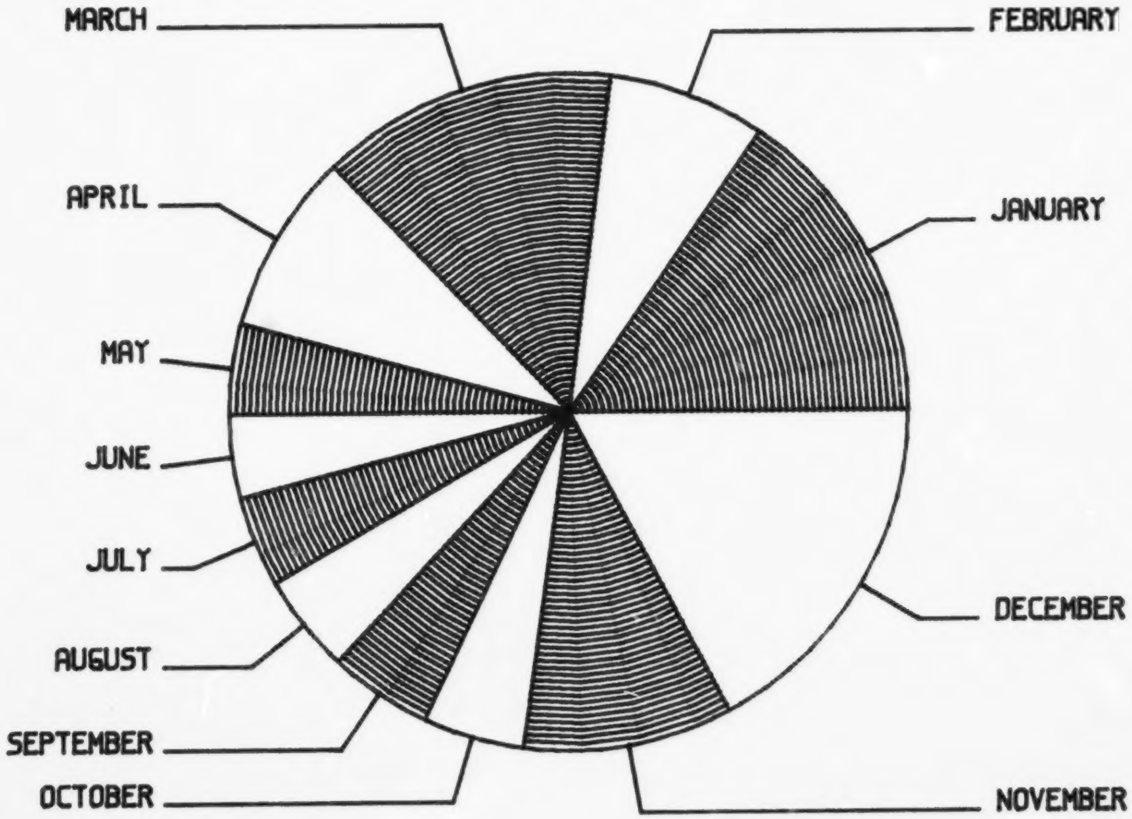

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FIGURE 5-13

LAKE HILLS RUNOFF FLOW (percent by month)

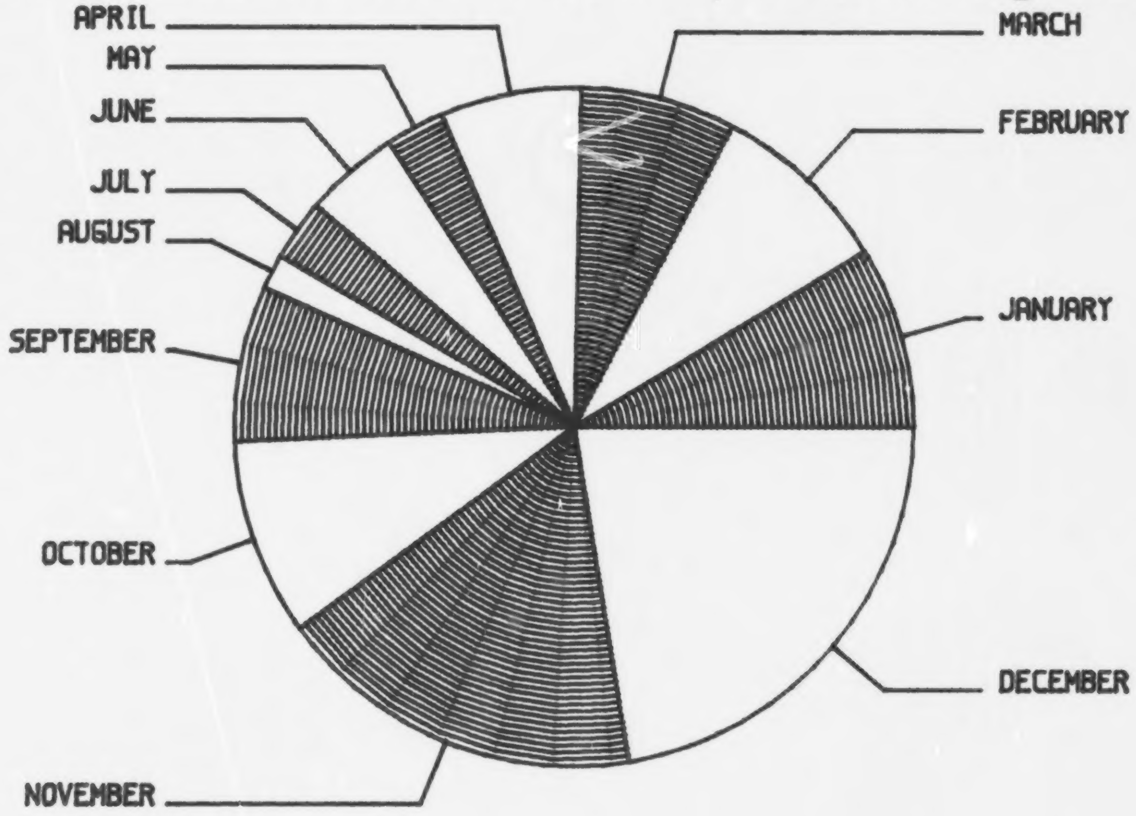

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Table 5-4. SURREY DOWNS AND LAKE HILLS BASE FLOWS AND RUNOFF FLOWS

	Surrey Downs		Lake Hills	
Month	Base flow (ft^3)	Total runoff (ft^3)	Base flow (ft^3)	Total runoff (ft^3)
2/80	—	—	35,050	293,940
3/80	127,455	233,662	69,870	315,440
4/80	62,728	178,230	51,720	285,240
5/80	50,410	84,137	23,632	73,165
6/80	48,040	165,870	22,610	204,500
7/80	47,830	18,950	21,850	17,530
8/80	50,130	68,960	27,780	91,550
9/80	50,660	97,160	30,900	145,200
10/80	47,120	47,880	22,830	56,210
11/80	89,880	553,920	44,730	817,790
12/80	110,350	625,215	87,235	879,800
Total	684,603	2,074,034	438,207	3,175,365
1/81	98,510	161,200	78,720	205,790
2/81	108,980	349,880	43,410	340,520
3/81	74,880	121,840	77,310	157,420
4/81	15,640	73,880	38,890	185,360
5/81	44,120	90,340	20,980	118,840
6/81	41,180	90,000	19,640	128,610
7/81	36,850	102,430	23,310	175,390
8/81	39,600	6,340	21,820	3,860
9/81	27,750	195,260	20,630	416,880
10/81	44,040	551,500	27,700	684,010
11/81	52,600	317,310	60,330	539,030
12/81	120,160	541,370	93,140	801,280
Total	704,310	2,601,350	525,880	3,756,990
1/82	66,780	216,100	82,150	357,600
Grand Total	1,455,693	4,891,484	1,046,237	7,289,955

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SECTION 6
URBAN RUNOFF QUALITY

INTRODUCTION

One of the principal tasks of the Bellevue urban runoff project was to collect samples representing as many runoff events as possible from the two test basins. About 200 rains occurred in each basin during the two year study period. Samples were collected for analyses from as many as 160 of these rains in each basin using automatic samplers and flow meters. Appendix E describes the sampling equipment and how it was used. The sampling equipment was set to initiate sampling at a predetermined runoff flow rate and to obtain flow weighted samples throughout the duration of the runoff event.

The sampling equipment was modified to discharge the samples into a single 50-gallon (190-liter) Nalgene container with plastic bottles containing ice as a preservative. Because of the large sample container, the sampling equipment was capable of collecting samples from small to very large rain events. The smallest rain event that was monitored was about 0.04 inches (1 mm) of rain. The largest rain events were more than four inches (100 mm). The large events did require some sampler servicing during the rain events. The smallest rains were represented by about six subsamples collected throughout the runoff period, while the large events contained several thousand runoff subsamples. The samples were removed from the sampling equipment within several hours of the end of the event. The chilled samples were then brought to the City of Bellevue's water quality laboratory where they were separated into different containers that had appropriate preservatives for the different chemical analyses. The Bellevue laboratory analyzed the samples for pH, turbidity, and specific conductance. The preserved samples were sent to a commercial laboratory in Seattle for analyses (Am Test, Inc.). The commercial laboratory analyzed the runoff samples for total solids, total Kjehldahl nitrogen (TKN), chemical oxygen demand (COD), lead (Pb), zinc (Zn), and total phosphorus (P).

The runoff monitoring equipment was installed in mid-March in Surrey Downs and in mid-April in Lake Hills in 1980. Because of some equipment problems at the beginning of the study period (due to the lack of event markers on the flow recorders) each station was temporarily deactivated for equipment modifications. Some small runoff events (less than 0.1 inch, or 2.5 mm) were not monitored because the automatic stage activator (which turned on the sampling equipment) could not detect small increases in runoff volumes, above the existing base flows, without many false starts. Therefore, only about three-fourths of all of the rain events were sampled. Because the larger runoff events were much more effectively sampled, a much larger percentage of the total runoff volume was sampled.

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During the period of runoff monitoring, street surface particulate samples were also collected and analyzed (as described in Section 7). The street cleaning program was varied during the runoff sampling program. The urban runoff data was therefore separated into different groups corresponding to the study areas, seasons, and street cleaning programs. Section 10 describes the street cleaning program and measurements in detail. Generally, extensive street cleaning was used in one basin for a period of time, without any cleaning in the other basin. After several months, this was reversed so that extensive street cleaning was conducted in the opposite basin. Over the two-year period of time, extensive street cleaning was conducted in each basin during both the wet and dry seasons. Periods of no street cleaning also occurred during the wet and dry periods in each basin. Runoff during a period of time was also monitored corresponding to no street cleaning in either basin at the same time. This schedule enabled the urban runoff quality and yield data to be compared on the basis of street cleaning effort and by season. Two extreme levels of street cleaning were used to simplify the analyses and to present extreme cases for comparison. The extensive street cleaning effort involved cleaning all streets in the drainage basin three times a week. This has been shown in previous studies (Pitt, 1979; and Pitt and Shawley, 1981) to result in streets nearly as clean as possible using conventional street cleaning equipment. More frequent street cleaning (every day or even multiple passes in a single day) may result in slightly cleaner streets, but at a much greater cost.

This section presents the urban runoff quality data by these study period divisions. This data is also compared to the preliminary Nationwide Urban Runoff Program (NURP) urban runoff quality data. The statistical distributions of the concentration data is examined and variations in runoff quality as a function of season are also shown. Baseflow samples are also discussed. The observed urban runoff quality data is compared to beneficial use water quality criteria. Calculated mass yields for the different storm events and estimated seasonal and annual discharges are also shown. The section finishes with a discussion of the potential source areas of the different urban runoff pollutants.

OBSERVED URBAN RUNOFF AND BASEFLOW QUALITY

Much urban runoff quality data was collected during this project. Tables A-8 through A-15 in Appendix A present the urban runoff quality data collected during this study representing completely monitored runoff events. Additional data was also collected for partial runoff events, but was not considered in the analyses because it could be misleading. Table 6-1 summarizes this observed data. Average, minimum, and maximum values for the water quality parameters, along with the flow and rain volumes, are shown for eight project periods. Most of the periods have from 20 to 30 monitored rain events. The Surrey Downs dry weather category unfortunately includes 51 data sets without street cleaning and only four data sets with street cleaning. Therefore, these two periods cannot be efficiently compared.

Table 6-2 compares this observed Bellevue runoff water quality with preliminary Nationwide Urban Runoff Program (NURP) data. The preliminary NURP

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Table 6-1. OBSERVED URBAN RUNOFF QUALITY (COMPLETE COMPOSITE STORM EVENT MEASUREMENTS ONLY)(mg/l)

	Runoff Volume (ft^3)	Rain (in)	Total Solids	TKN	COD	Total Phos.	Lead	Zinc	pH	Spec. Cond. (µmhos/cm)	Turb (NTU)
Lake Hills Dry Weather - Without Street Cleaning											
average	28,400	0.36	110	1.4	54	0.42	0.25	0.14	6.1	42	15
minimum	1,210	0.04	24	<0.5	13	0.015	<0.1	0.067	5.3	22	6
maximum	132,000	1.33	270	5.9	120	3.6	0.56	0.29	6.6	140	35
number of events: 23											
- With Street Cleaning											
average	16,800	0.27	110	1.1	44	0.28	0.17	0.12	6.1	30	24
minimum	2,880	0.08	27	<0.5	20	0.1	<0.1	0.061	5.2	17	6
maximum	36,900	0.53	240	4	120	1.2	0.5	0.26	7	61	67
number of events: 24											
Lake Hills Wet Weather: - Without Street Cleaning											
average	61,400	0.50	78	0.66	32	0.14	0.11	0.094	6.6	40	16
minimum	3,060	0.07	33	<0.5	17	0.071	<0.1	0.03	5.5	22	6
.maximum	209,000	1.58	230	1.4	77	0.34	0.4	0.22	7.1	85	82
number of events: 32											
- With Street Cleaning											
average	45,200	0.45	130	1.0	43	0.30	0.18	0.11	6.0	31	38
minimum	2,590	0.11	27	<0.5	13	0.026	<0.1	0.053	5.5	19	17
maximum	223,000	1.55	440	3.8	83	0.92	0.31	0.23	6.8	55	150
number of events: 20											
Surrey Downs Dry Weather - Without Street Cleaning											
average	18,600	0.34	130	1.3	61	0.32	0.18	0.14	6.2	38	16
minimum	1,260	0.05	31	<0.5	21	0.068	<0.1	0.07	5.2	16	4
maximum	108,000	1.65	620	4.3	150	1.2	0.82	0.37	7.4	95	41
number of events: 51											
- With Street Cleaning											
average	39,700	0.65	120	1.2	40	0.29	0.85	0.13	--	--	--
minimum	8,590	0.18	43	0.5	15	0.097	0.21	0.093	--	--	--
maximum	78,800	1.18	200	2.7	54	0.59	<0.1	0.2	--	--	--
number of events: 4											

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Table 6-1. OBSERVED URBAN RUNOFF QUALITY (cont.)

Surrey Downs Wet Weather

	Runoff Volume (ft^3)	Rain (in)	Total Solids	TKN	COD	Total Phos.	Lead	Zinc	pH	Spec. Cond. (μmhos/cm)	Turb (NTU)
- Without Street Cleaning											
average	50,100	0.57	95	0.84	43	0.17	0.12	0.13	6.3	46	16
minimum	2,460	0.04	29	<0.5	19	0.002	<0.1	0.047	5.7	23	5
maximum	250,000	2.2	270	2.0	110	0.38	0.4	0.31	7.0	110	67
number of events:	34										
- With Street Cleaning											
average	56,300	0.69	100	0.77	34	0.15	0.11	0.10	6.9	64	16
minimum	3,980	0.08	64	0.48	17	0.075	<0.1	0.059	6.3	29	5
maximum	401,000	4.38	190	1.8	69	0.28	0.2	0.16	7.3	300	42
number of events:	20										

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Table 6-2. BELLEVUE RUNOFF WATER QUALITY COMPARED TO NATIONWIDE (NURP) DATA

	Lake Hills				Surrey Downs				All NURP Data (as of 10/81)			
Constituents	min	max	median	# of obser	min	max	median	# of obser	min	max	median	# of obser
pH	5.2	7.1	6.2	94	5.2	7.4	6.3	98	2.8	10.1	7.0	1608
turbidity (NTU)	6	150	17	96	4	67	14	102	0.2	4900	51	1153
Spec. cond. (μmhos/cm)	17	140	32	93	16	300	38	100	1.0	4400	330	4335
total solids (mg/l)	24	440	87	98	29	620	95	107	21	23,700	340	2411
Chemical Oxygen Demand (mg/l)	13	120	36	99	15	150	42	106	0.3	1430	52	679
Total Kjeldahl Nitrogen (mg/l)	<0.5	5.9	0.78	99	<0.5	4.3	0.84	105	0.01	520	2.0	4521
Total Phosphorous (mg/l)	0.015	3.6	0.19	99	0.003	1.2	0.17	106	<0.01	85	0.43	4909
Lead (mg/l)	<0.1	0.56	0.10	99	<0.10	0.82	0.10	106	<0.01	30	0.23	4574
Zinc (mg/l)	0.030	0.29	0.11	99	0.047	0.37	0.11	106	<0.01	26	0.23	3610

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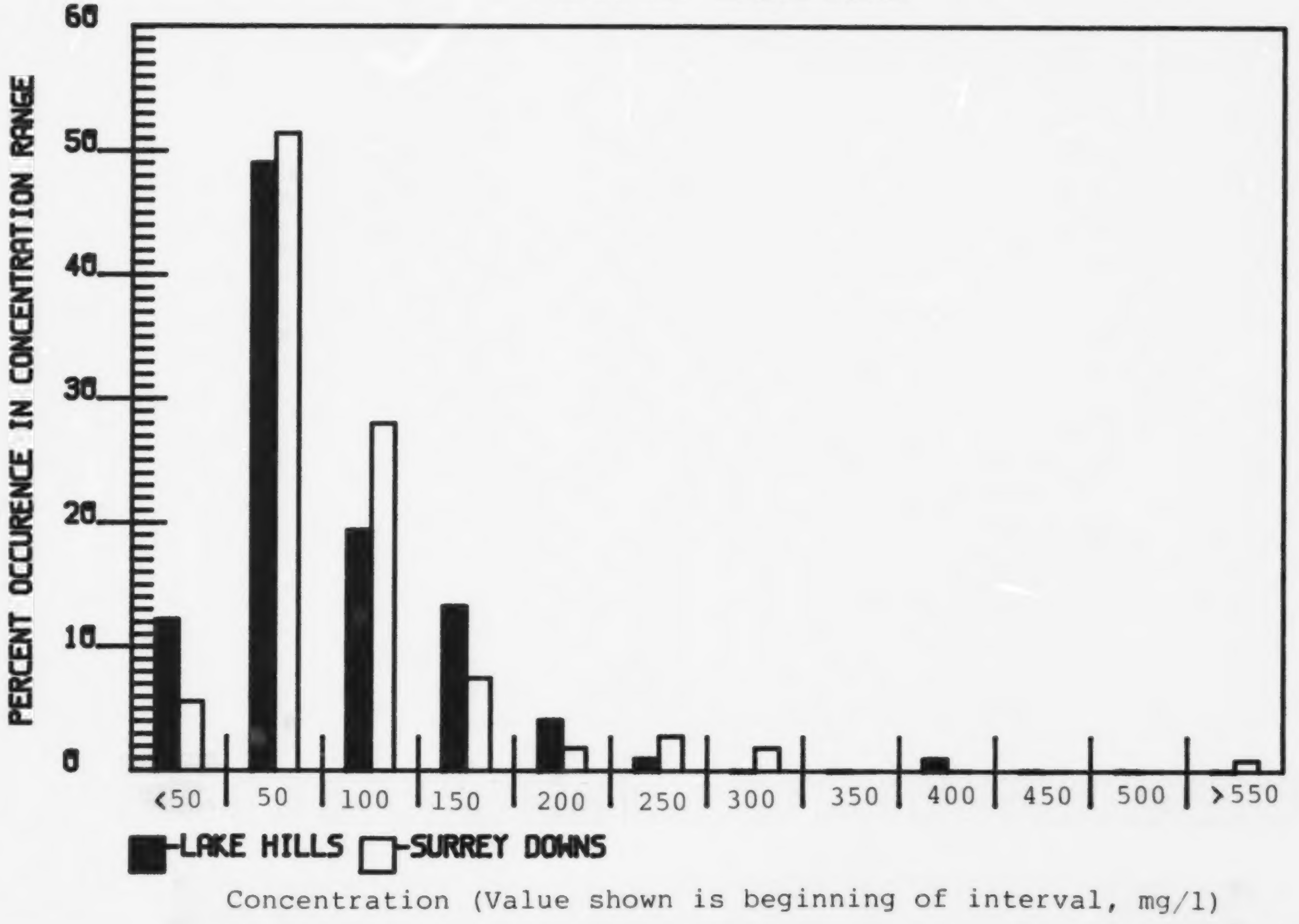
data was available as of October, 1981, and included data from many urban runoff monitoring locations throughout the country. The Bellevue urban runoff is of much better quality than typically found elsewhere. The median Bellevue runoff water quality constituent concentrations are about half of the average NURP concentration values reported. The Bellevue specific conductance values are about one-tenth of the NURP average values. The amount and type of rain at Bellevue, along with the urban land-use development practices were probably responsible for these lower observed concentrations. The annual rainfall at Bellevue (about 34 inches, or 860 mm) is not that much different from the annual rainfalls at many of the NURP project sites. However, the typical Bellevue rains are much smaller than elsewhere, with many more rains occurring in a year, and with resultant shorter interevent periods. With a short interevent period, pollutants have a shorter time to accumulate. In addition, the smaller rains at Bellevue do not possess enough energy to remove much of the deposited pollutants in the urban areas. The ranges of the NURP event mean concentration values are quite large and the Bellevue median values are closer to the minimum than the maximum values. The much larger range in reported NURP concentrations, compared to Bellevue concentrations, is due to the much broader range of conditions and the larger number of observations included in the NURP data base.

The distributions of the observed concentrations for total solids is shown in Figure 6-1. Distributions for the other constituents are shown in Figures A-16 through A-23 in Appendix A. Those distributions show that the most commonly observed concentrations for each constituent are much closer to the low side of the observed range than for the higher values. This is quite common in many physical measurements that cannot have negative values. Minimum values are bounded by the zero value, while there is no absolute limit to the upper values. Periodically, very large values may be observed due to unusual circumstances. The distribution for pH values in Figure A-21, however, shows a more "normal" distribution with the most common value centered in the observed range. This is because pH is a measure of the hydrogen ion concentrations in the water expressed as a negative log to the base ten. This implies that the distribution of concentration observations may be expressed as a log-normal distribution. The actual form of the distribution is important because it defines and restricts the use of certain statistical tests that can be used to indicate differences and similarities in the data. Many of the common statistical analyses (including least squares linear regression analyses to determine an equation that fits the data points, and Student's "T" test which indicates significant differences in paired or unpaired data sets) require normally distributed values and equal variances along the range of observations. If the data can be transformed to fit a normal pattern, then these basic and powerful statistical analyses procedures can be legitimately used.

Figure 6-2 shows a log-probability plot of total solids concentration values. Figures A-24 through A-30 in Appendix A shows the log-probability plots for the other constituents (except pH). A straight line on normal probability charts indicate a normal distribution of the observed data. When the logarithmic transformation is made, nearly straight lines result for all of the constituents, especially between the probability ranges of five and 95 percent on the log-normal charts. In some cases, a straight line occurs from

FIGURE 6-1

TOTAL SOLIDS



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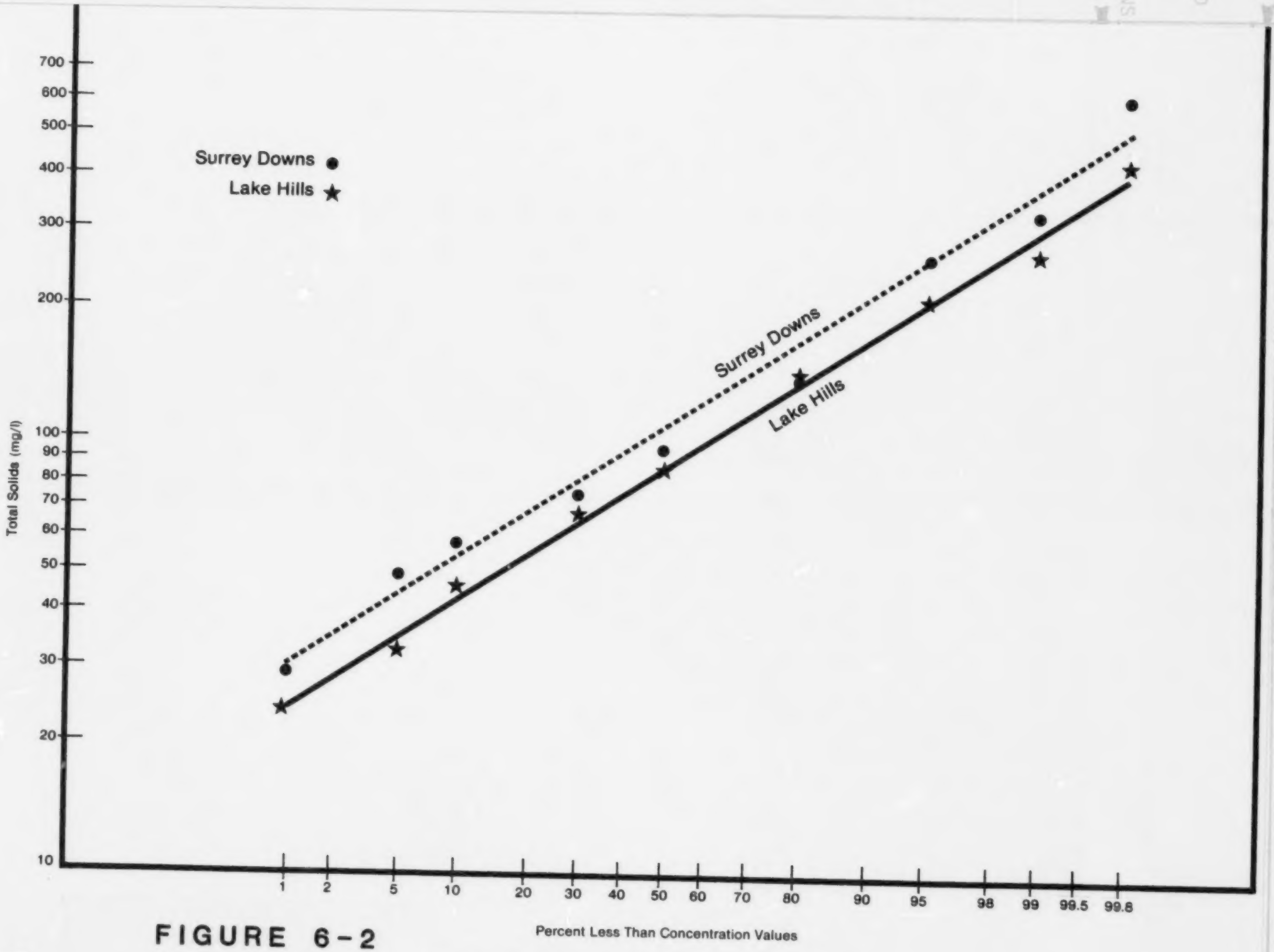

FIGURE 6-2

Frequency Distribution of Total Solids Concentrations

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the one to 99 percent probability values. In many cases, however, the extreme low or high values do not fall on the straight line. This can be expected because of the relatively small number of observations in each data set. However, these small deviations in the extreme tails of the observations do not significantly alter the conclusions associated with the statistical tests.

The previous bar graph non-transformed distribution plots and these log probability plots show the observations for Surrey Downs and Lake Hills separately. For total solids, COD, zinc, and specific conductance, the Surrey Downs concentrations are greater than the Lake Hills concentrations. No noticeable difference appears for the other constituents over the entire range of constituent concentrations observed.

Concentrations also varied by month. Table 6-3 shows the average monthly runoff concentrations observed for both the Lake Hills and Surrey Downs sites. A general cycling of the concentrations was observed: the concentrations were typically greater during the dry months than during the wet months. These variations may have been caused by differences in the rain characteristics (especially rain totals and frequencies) during the seasons. If the pollutants are source limited in the drainage basin, then the larger rain events would result in lower runoff concentrations. This, of course, requires that the small rain events have sufficient energy to remove the contaminants from the drainage basin. Some of the pollutants, such as lead on street surfaces, may be considered source limited, but other pollutants, especially total solids, could not be considered source limited because erosion potential usually increases with increasing rains.

Figures A-31 through A-38 in Appendix A are plots of observed runoff concentrations as a function of rain magnitude for each of the two basins and for the wet and dry seasons. The most common feature of all of these scatter plots (with the exception of the pH plots) is that the maximum observed concentrations occur for rains smaller than about 0.5 or 0.75 inch (13 or 19 mm). The concentrations of the runoff associated with rains greater than these volumes fall into a much narrower band. The small rain events, however, also contain many low mean event concentration values. These relationships signify a dilution effect by the larger rains and an uneven amount of energy to remove pollutants by the smallest rains, caused by varying rain intensities. Even though the large rains observed include the largest rains that are likely to occur in the area, increases in total solids or other contaminants associated with pervious areas did not occur. In other areas that experience much larger rains, increases in total solids concentrations may be evident for the very largest rains. These scatter plots also differentiate observations obtained during dry and wet periods. Generally, the highest concentrations for almost all of the rain volumes are associated with the dry seasons. However, many wet season observations are also relatively high. Again, the dry season rains would have long periods of pollutant accumulations between them.

Baseflow samples were collected about once a month during the second year of the project. These baseflow samples were collected using the automatic samplers on a time sampling mode. The samples represent average

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Table 6-3. AVERAGE MONTHLY RUNOFF CONCENTRATIONS (mg/1)

	Total Solids		COD		TKN		TP		Lead		Zinc	
	LH	SD	LH	SD	LH	SD	LH	SD	LH	SD	LH	SD
Jan	120	126	39	50	0.67	0.81	0.24	0.16	0.18	0.16	0.095	0.11
Feb	112	93	38	46	0.86	0.75	0.26	0.18	0.20	0.12	0.089	0.090
Mar	69	95	36	48	0.83	0.75	0.14	0.19	0.10	0.13	0.094	0.11
Apr	89	110	37	43	0.88	1.0	0.26	0.27	0.16	0.17	0.095	0.11
May	130	110	46	67	0.97	1.2	0.21	0.26	0.21	0.13	0.12	0.13
June	115	170	51	74	1.4	1.7	0.34	0.46	0.24	0.22	0.13	0.16
July	98	120	45	60	1.0	1.1	0.26	0.23	0.16	0.14	0.11	0.14
Aug	130	270	86	100	3.7	2.4	1.5	0.75	0.37	0.44	0.23	0.25
Sept	130	130	54	56	1.3	1.3	0.30	0.28	0.23	0.17	0.15	0.15
Oct	90	100	42	39	1.2	1.0	0.20	0.19	0.16	0.11	0.11	0.11
Nov	100	86	37	40	0.79	0.94	0.25	0.17	0.12	0.11	0.11	0.13
Dec	81	94	32	36	0.68	0.63	0.14	0.14	0.11	0.11	0.094	0.11

baseflow concentrations over about 24 hours of time. Table 6-4 summarizes the baseflow water quality observations at the two sampling sites. The observed baseflow concentrations of COD, TKN, total phosphorus, lead, and zinc were about the same as for the storm runoff concentrations. However, the baseflow total solids and specific conductance values were much greater than observed in the storm runoff. The total solids material during storm runoff events is mostly suspended solids, while the total solids during baseflow conditions is mostly dissolved solids (based on ratios of specific conductance to total solids). The similarities in baseflow and storm runoff nutrient and heavy metal concentrations is surprising. In other areas (especially at the Castro Valley NURP site; Pitt and Shawley, 1981) the baseflow and nutrient concentrations were much less than the storm runoff concentrations. However, the Castro Valley baseflow dissolved solids, specific conductance, and major ion concentrations were all much greater than observed in the storm runoff. In Castro Valley this implied that the baseflow was mostly associated with discharging groundwater that originated in non-urban areas above the study area. At the two Bellevue sites, however, the complete basins are urbanized and the groundwater that discharges to the storm drainage systems between rain events was much more contaminated than the rural groundwater discharges observed at Castro Valley.

The nutrient and heavy metal urban runoff concentrations at Bellevue are much less than observed at other NURP project sites. The Bellevue baseflow concentrations are also much less than the average NURP runoff data, except for total solids and specific conductance. In a later subsection, the contribution of baseflow discharges will be compared to the annual storm runoff discharges.

Additional Bellevue urban runoff information is included in the USGS report on their portion of the Bellevue urban runoff project (Prych and Ebbert, undated). The USGS used elaborate samplers that collected many runoff samples at different time intervals during rain events. They analyzed many samples for their monitored rain events for many more constituents than were included in this program phase. However, the USGS sampled many fewer rain events than included in this project.

Seattle METRO (Galvin and Moore, 1982) is also conducting a project associated with the Bellevue urban runoff program. METRO's study is directed towards monitoring priority pollutants is urban runoff, urban runoff source areas, and receiving waters. These priority pollutants include many pesticides and industrial chemicals that have been shown to be carcinogenic. Several heavy metals are also included as priority pollutants.

COMPARISON OF OBSERVED URBAN RUNOFF CONSTITUENT CONCENTRATIONS WITH WATER QUALITY CRITERIA

Published water quality criteria are not really appropriate for urban runoff problem identification. These criteria, even when expressed in terms of safety factors for organisms present in the receiving waters, are designed for continuous discharges and relatively constant concentrations. In most locations, receiving water pollutant concentrations during periods of runoff

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Table 6-4. Base Flow Quality

	Lake Hills				Surrey Downs			
Constituent	Min. mg/l	Max. mg/l	Average mg/l	# of Samples	Min. mg/l	Max. mg/l	Average mg/l	# of Samples
Total Solids	108	326	210	13	130	226	193	13
COD	9.1	67	27	13	6.8	45	19	13
TKN	0.20	1.9	0.56	13	0.34	2.4	1.0	13
TP	0.027	0.22	0.11	13	0.034	1.2	0.20	13
Lead	<0.1	0.1	<0.1	13	<0.1	0.1	<0.1	13
Zinc	0.03	0.14	0.073	13	0.026	0.47	0.10	13
Spec. Cond (μmhos/cm)	138	430	270	9	146	300	240	9

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vary dramatically from the baseflow concentrations. In most cases, the slugflow nature of storm runoff cannot be compared to the water quality criteria that are associated with continuous discharges. However, as was noted in the last subsection, the baseflow and storm runoff concentrations in Bellevue are not that dissimilar, except for total solids. The published criteria may, therefore, be applicable when evaluating the storm runoff discharge conditions at Bellevue, especially for "totally developed" watersheds. Another important project associated with the Bellevue urban runoff program was conducted by the University of Washington (Pedersen, 1981; Richey, 1982; and Scott, Steward, and Stober, 1982) through the Corvallis Lab of the EPA and addressed receiving water measurements and effects from urban runoff. The University of Washington study included actual beneficial use impairment measurements by sampling the aquatic organisms most directly affected by urban runoff. The observed biological conditions in selected Bellevue urban runoff receiving waters were compared to the biological conditions in similar bodies of water unaffected by urban runoff. This subsection will compare published water quality criteria with urban runoff concentrations observed during this study. Refer to the University of Washington study for a more detailed discussion of probable urban runoff effects at Bellevue.

Dissolved Oxygen

No dissolved oxygen measurements of urban runoff were obtained during this study. Previous studies show that the DO of urban runoff is near saturation due to the turbulence and thin sheet flow nature of most urban runoff source waters. However, urban runoff contains various chemicals and organic matter that can consume oxygen in the receiving water over a period of time. Urban runoff can be characterized as a wastewater having low levels of organic matter and nutrients and high levels of heavy metals and possibly other directly toxic materials. Urban runoff has been found to exert small immediate oxygen demands on receiving waters due to the low residence time of the wastes in the receiving waters and the non-biodegradability of the oxygen consuming material. A previous study (Pitt, 1979) found that the long-term oxygen demand of urban runoff can be many times greater than the short-term oxygen demand usually measured. This long-term increase in oxygen demand is probably associated with initial toxic effects of the urban runoff heavy metals affecting the microorganisms that break down the organic material and consume oxygen. This long-term oxygen demand is important when deposition of urban runoff sediments occur in the receiving waters. These sediments can exert significant oxygen demands associated with urban runoff materials long after the storm runoff event has ended. Therefore, instream dissolved oxygen concentration and sediment oxygen demand analyses are much more significant in evaluating the oxygen demanding effects associated with urban runoff than urban runoff oxygen demand measurements. Urban runoff COD measurements were made as part of this study to supplement the instream measurements of oxygen demanding material included in the University of Washington study.

Dissolved oxygen has always been an important indicator of water quality. Insufficient dissolved oxygen can cause anaerobic decomposition of organic materials which can in turn cause the formation of noxious gases, such as hydrogen sulfide, and the development of carbon dioxide and methane in the sediments. Dissolved oxygen in the water column can also cause chemical oxidation and subsequent leaching of iron and manganese from sediments. The effects of dissolved oxygen on freshwater fish is complicated because fish vary in their oxygen requirements according to the specific species, their age, activity, water temperature, and by the amount of food present. Fish are capable of surviving for short periods of time at very low oxygen conditions. Most researchers, however, report a dissolved oxygen concentration of at least four mg/l needed to support a varied fish population. However, greater concentrations will usually result in a greater variety of species present. Fish embryonic and larval stages are especially vulnerable to low oxygen conditions because of their lack of mobility. In addition, low dissolved oxygen levels can adversely affect aquatic insects and other animals upon which fish feed. As long as dissolved oxygen concentrations remain sufficient for fish, no significant impairment of the fish's resources, due to dissolved oxygen, are likely to occur.

Solids

Observed total solids concentrations in the storm runoff during this study varied from about 20 to more than 500 mg/l. The average event mean concentration value was slightly less than 100 mg/l. The total solids concentrations during baseflow conditions averaged about twice these concentrations. The total solids during storm runoff events are mostly made up of suspended solids while the total solids during baseflow conditions are mostly made up of dissolved solids. Much of the so-called suspended solids during urban runoff events may settle out in the receiving water as sediments.

The criteria for suspended solids and aquatic life beneficial uses is usually considered about 80 mg/l. This is about equal to the observed total solids concentrations during most of the urban runoff events in Bellevue. The total dissolved solids criteria varies appreciably depending upon the resistance of the aquatic species and other uses. This total dissolved solids criteria is usually associated with restricting the salinity of the water and would usually be much greater than observed during the storm runoff events or during baseflow. Therefore, the most important effects of solids is associated with the suspended solids during storm runoff events and the accumulation of settleable solids on the stream beds.

Suspended solids can affect fish life in several ways; by directly killing the fish, or by reducing their growth rate or their resistance to disease, for example. Suspended solids also affect fish by limiting successful development in fish eggs and larvae. Suspended solids can also modify natural movement and migration of fish and can reduce the abundance of fish food available. The most direct effects of suspended solids are the reduction of light penetration into the water column and the heating of the surface waters. Settleable materials associated with urban runoff solids blanket the bottom of waterbodies and damage the invertebrate populations, ruin gravel spawning beds, and, if they are organic, can remove substantial quantities of dissolved oxygen from overlying water. The most important effect of urban runoff solids in Bellevue receiving waters is probably the contribution of settleable silts and clays covering the gravel spawning beds. The abrasion of fish gills by the solids may also be important.

Nitrogen

The only form of nitrogen monitored by this urban runoff project was total Kjeldahl nitrogen, which is a combination of the organic nitrogen forms and ammonia. The most common forms of nitrogen not included in this analysis are nitrates and nitrites. Organic nitrogen may make up most of the total Kjeldahl nitrogen in some cases, and ammonia may be more prevalent in other cases. The un-ionized ammonia (ammonium) form of nitrogen ammonia is toxic to aquatic organisms. This un-ionized ammonium is usually less than about 25 percent of the total ammonia concentrations in the urban runoff. Average ammonia concentrations in Bellevue storm runoff and baseflow would be much less than several hundred micrograms per liter. However, the maximum observed total Kjeldahl nitrogen concentrations, as high as about six mg/l, signify the potential for high ammonia concentrations. At these very high total Kjeldahl nitrogen concentrations, the un-ionized ammonium concentrations may be several hundred micrograms/liter.

Rainbow trout have been reported to be the most sensitive fish to un-ionized ammonium (the most toxic form of ammonia). Concentrations of 0.2 mg/l ammonium are lethal to rainbow trout, while values less than this can exert adverse physiological or histopathological effects. At concentrations of three mg/l total ammonia, trout have been reported to become hyperexcitable and, at eight mg/l total ammonia, 50 percent of the trout died within 20 hours. Carp are usually the least sensitive fish to ammonium. Sublethal exposures to ammonium can cause extensive necrotic changes and tissue degradation in various organs. Concentrations of 2 mg/l un-ionized ammonium can be lethal to carp (EPA, 1976). The observed total Kjeldahl nitrogen concentrations indicate the potential for some adverse ammonium concentrations, but this would likely be restricted to rare runoff events. The typical storm runoff concentrations do not indicate recurring ammonia toxicity problems.

Nitrate concentrations in storm runoff may also be important. Even though not included in the total Kjeldahl nitrogen analyses, the presence of large amounts of organic nitrogen and ammonia may indicate high nitrate concentrations. Nitrate is a common major ion and was monitored as part of the USGS monitoring program. Preliminary results from the USGS (Ebbert, Poole, and Payne, 1983) show nitrate concentrations of about 0.025 mg/l. Maximum concentrations of several mg/l were also observed.

The 96-hour concentration of nitrates capable of killing half of the bluegills in a test (96-hr LC-50) was two mg/l, while a value of 0.09 mg/l nitrate plus nitrite had no significant effect on growth or feeding habits of largemouth bass and channel catfish (EPA, 1976). However, rainbow trout are much more susceptible to nitrate concentrations. Trout weighing 200 grams experienced no mortalities after ten days with nitrate plus nitrite

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concentrations of 0.06 mg/l. Smaller two-gram rainbow trout did not experience any mortalities after being exposed to 0.14 mg/l nitrate plus nitrite for ten days, but 12-gram rainbow trout experienced an 8-day lethal concentration of about 0.15 mg/l. In another study, four sizes of rainbow trout had LC-50 toxicity values after 96-hour exposures in hard water of 0.19 to 0.3 mg/l nitrate plus nitrite. Fingerling rainbow trout experienced a 50 percent mortality after 24 hours exposure (24 hour-LC 50) to 1.6 mg/l nitrate plus nitrite, and yearling rainbow trout experienced a 55 percent mortality after 24 hours at concentrations at 0.55 mg/l. Carp are more tolerant and survived 48-hour exposures to 40 mg/l. Mosquito fish experienced 96-hour LC-50 toxicity values of about 1.5 mg/l (EPA, 1976). Therefore, there is some potential for nitrate concentrations affecting the receiving water trout populations.

Phosphorus

Total phosphorus concentrations were about 0.2 mg/l during storm runoff events and could be as high as several mg/l. The EPA (1976) recommends a maximum value of 0.1 mg/l total phosphorus for streams to prevent plant nuisance growths (eutrophication). They also note that most uncontaminated lakes have surface water phosphorus concentrations of less than 0.03 mg/l. Therefore, almost all of the observed phosphorus concentrations are capable of creating nuisance algae growths in calm waters.

Lead

Most of the lead concentrations were about 0.1 mg/l in the storm runoff while they were undetectable (less than 0.1 mg/l) during baseflow. Unfortunately, the detection limit for the lead analysis procedure used was 0.1 mg/l. During the early parts of the urban runoff program, almost all of the lead concentrations reported were greater than this detection limit. However, near the end of the program, during periods of larger rain volumes, the reported lead concentrations were frequently below the detection limits. The highest lead concentrations observed approached one mg/l.

Fathead minnow 24- to 96-hour LC-50 values of 480 mg/l have been reported, using lead chloride and from one to two gram, 38 to 64 millimeter, fathead minnow specimens. A 96-hour LC-50 value for rainbow trout in very hard water was also about 470 mg/l. However, 0.12 to 0.36 mg/l lead nitrate was the highest concentration not having adverse effects on survival, growth, and reproduction of rainbow trout. Concentrations of free lead of 1.4 mg/l and total lead of 470 mg/l are LC-50, 96-hour values for rainbow trout. Organic methylated forms of lead can be much more toxic to fish. The LC-50, 24-hour and 48-hour values for bluegills in hard water ranged from 1.4 to 2.0 mg/l organic lead for one- and two-gram fish. Similar exposure times of lead chloride produced much greater LC-50 values of about 450 to 500 mg/l (EPA, 1976).

The dissolved lead concentration values that have been shown to be lethal to fish are much greater than the dissolved lead concentrations expected in the Bellevue urban runoff or receiving waters. A small fraction of total lead that was observed in the Bellevue urban runoff is expected to occur as either organic lead forms or other soluble lead forms. However, the accumulation of particulate lead forms in sediments receiving urban runoff has been shown to potentially cause adverse effects on the benthic organisms (Pitt and Bozeman, 1982).

Zinc

The observed total zinc concentration in the Bellevue urban runoff was about 0.1 mg/l and maximum values were about 0.4 mg/l. The baseflow concentrations were slightly less.

Rainbow trout have been reported to be the most sensitive fish to zinc in hard waters, with lethal concentrations for coarse fish being three to four times the rainbow trout values. Immature insects seem to be less sensitive than many of the test fish. For fathead minnows, 96-hour LC-50 values in hard water were reported to be 33 mg/l. However, at the much-reduced zinc concentration of 0.18 mg/l, an 83 percent reduction in egg production was found, as compared to a zinc concentration of 0.03 mg/l. One to two gram fathead minnows had 96-hour LC-50 values of 8.2 to 21 mg/l anhydrous zinc sulfate. Fathead minnow eggs experienced 24- to 96-hour LC-50 values of 1.8 to 4.0 mg/l, also with anhydrous zinc sulfate. Fathead minnow fry 24- to 96-hour LC-50 values were less, at 0.87 to 0.95 mg/l anhydrous zinc sulfate. Two to three gram fathead minnows 96-hour LC-50 values were greater, at about nine to 13 mg/l anhydrous zinc sulfate. Juvenile rainbow trout 96-hour LC-50 values in hard water were about 7.2 mg/l zinc sulfate and were reduced to 3.2 mg/l for 48-hour exposures to elemental zinc. One to two gram bluegills experienced 24- to 96-hour values of about 41 mg/l anhydrous zinc sulfate (EPA, 1976)

The observed total zinc urban runoff concentrations in Bellevue are less than most of the reported dissolved zinc concentrations that may cause potential problems. As for most heavy metals, EPA recommends a water quality criteria value of 0.01 of the critical LC-50 values for the aquatic organisms present. Again, since most of this total zinc is in a particulate form, the dissolved zinc levels in the urban runoff and baseflows are still likely to be less than these more critical values. However, settleable particulates may contain these relatively high zinc concentrations and may cause long-term adverse effects for the benthic organisms in the sediments.

Summary

It is evident from the preceding discussion that the forms of many of the water quality constituents determine their toxicities. During a previous urban runoff study in San Jose, California (Pitt, 1979), typical urban runoff constituent concentrations for a broad list of common ions and heavy metals

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were analyzed using an equilibrium water chemistry computer program. This program was used to estimate the specific inorganic chemical compounds that were probably present in the urban runoff and to estimate which pollutants would probably remain soluble and which pollutants would probably accumulate in urban runoff sediments.

Most of the urban runoff pollutants were predicted to be in soluble forms and would, therefore, be carried in the water column. However, this was not the case for some pollutants. For example, 95 percent of the inorganic lead was predicted to be insoluble. Depending upon the size of these particles (or the particles to which they may become attached), the lead could remain in suspension or could settle out in the storm drainage system and/or the receiving waters. Chromium and phosphate may also settle out. The settling of lead particles to the sediments was substantiated in field studies in San Jose, as relatively high concentrations of lead were found in urban Coyote Creek sediments (Pitt and Bozeman, 1982).

The soluble fractions of other inorganic constituents monitored were primarily insoluble ionic forms, including calcium, magnesium, sodium, potassium, sulfate, chloride, and nitrates. Most of the carbon dioxide is expected to be in bicarbonate forms. Most of the phosphate is expected as soluble phosphoric acid, but important fractions of phosphate may occur as insoluble calcium phosphate and lead phosphate forms. Almost all of the lead is expected to be in particulate lead carbonate or lead phosphate forms, with only a few percent of the lead occurring as soluble lead ions or soluble lead carbonate forms. Almost all of the zinc and copper are expected to occur as soluble ionic forms, while the chromium is expected to occur as soluble chromium hydroxide.

This computer analysis considered equilibrium conditions and only inorganic forms. Urban runoff is definitely not at chemical equilibrium and many organics are also present. However, long-term sediment conditions are in equilibrium and many organic complexities have small effects on solubility. These expected chemical forms can be used as guidelines when estimating the potential for toxic materials to accumulate in sediments.

In summary, direct urban runoff receiving water effects during runoff events may not be significant. Potential immediate dissolved oxygen demand is balanced by the supersaturated oxygen conditions in urban runoff. In special conditions, dissolved oxygen during runoff events may be important.

Suspended solids concentrations during runoff events may not be important, except for infrequent very high suspended solids concentrations. Ammonium and nitrate nitrogen concentrations may periodically be in adverse concentrations during storm events. Most of the Bellevue urban runoff water quality problems are expected to be associated with long-term problems caused by settled organic and inorganic debris and particulates. This material can silt up salmon spawning beds in the Bellevue streams and introduce high concentrations of toxic materials directly to the sediments. Oxygen depletion caused by organic sediments and the lead and zinc concentrations in the sediments may all affect the benthic organisms. These benthic organisms are important food for the fish in the receiving waters and they may be adversely

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affected over long periods of time. Drastic changes in benthic organism populations and the absence of desirable fish have been noted in other urban runoff receiving water studies (Pitt and Bozeman , 1982).

MASS YIELDS OF POLLUTANTS FROM URBAN AREAS

The urban runoff quality data and the runoff volume data presented earlier were used to calculate the urban runoff pollutant mass yields for each rain event monitored. Tables A-16 through A-23 in Appendix A list these calculated values for the different drainage basins, seasons of the year, and periods of different street cleaning practices. These yield values occurred over wide ranges because of the wide ranges of runoff volumes and concentrations observed. Table 6-5 summarizes the estimated annual mass yields for baseflow and runoff in both basins. The observed runoff yields from the monitored storms were used to predict the expected runoff yields from the storms that were not monitored. The urban runoff annual discharges shown on this table are based on about 75 percent direct measurements and about 25 percent estimates. The baseflow values are based on the two-year baseflow volumes between all storm events but only on the year two baseflow quality concentrations.

There is an apparent difference between the runoff discharges in Lake Hills and Surrey Downs when expressed on a pounds per acre basis. However, the total annual runoff plus baseflow discharges from the two basins are quite similar. This implies that a much larger fraction of the total urban runoff in Surrey Downs occurs as baseflow between rain events. The runoff events in Lake Hills are more sharply defined and the Lake Hills baseflow is a much smaller fraction of the total urban mass yields.

The estimated annual mass yields of the urban pollutants expressed in pounds per acre per year are similar to those reported in San Jose, California (Pitt, 1979), and in Castro Valley, California (Pitt and Shawley, 1982). The much smaller urban runoff pollutant concentrations observed in Bellevue when compared to these other two locations is compensated for by the much larger amount of runoff that occurred.

Figures 6-3 and 6-4 show the variations of the annual runoff and baseflow mass yields by month for total solids in the two basins. May through August only contributed about five percent of these annual mass yields in each month. November and December each contributed between 15 and 20 percent of the annual mass yields. The contributions of runoff and baseflow volumes were greater in those months that had high runoff volumes. The runoff and baseflow concentrations for many pollutants were similar. The effects of different flow volumes on total runoff yields for each event was also studied.

Figures 6-5 through 6-8 show variations for total solids and lead for both Lake Hills and Surrey Downs. These scatter plots show log transformed values of flow versus log transformed values of storm yields. These log transformations were necessary to even out the observed data distribution. These transformed distributions were analyzed using curve fitting routines

Table 6-5. Annual Urban Runoff Mass Yields (lbs/acre/year)

Constitutent	Lake Hills base flow	 storm runoff	 total	Surrey Downs base flow	 storm runoff	 total
Total Solids	67	250	320	100	180	280
COD	8.7	100	110	10	79	89
TKN	0.18	2.4	2.6	0.53	1.6	2.1
TP	0.035	0.61	0.65	0.10	0.35	0.45
Lead	0.02	0.40	0.42	0.03	0.23	0.26
Zinc	0.024	0.27	0.29	0.053	0.21	0.26

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FIGURE 6-3

LAKE HILLS - Total Solids Yield by Month

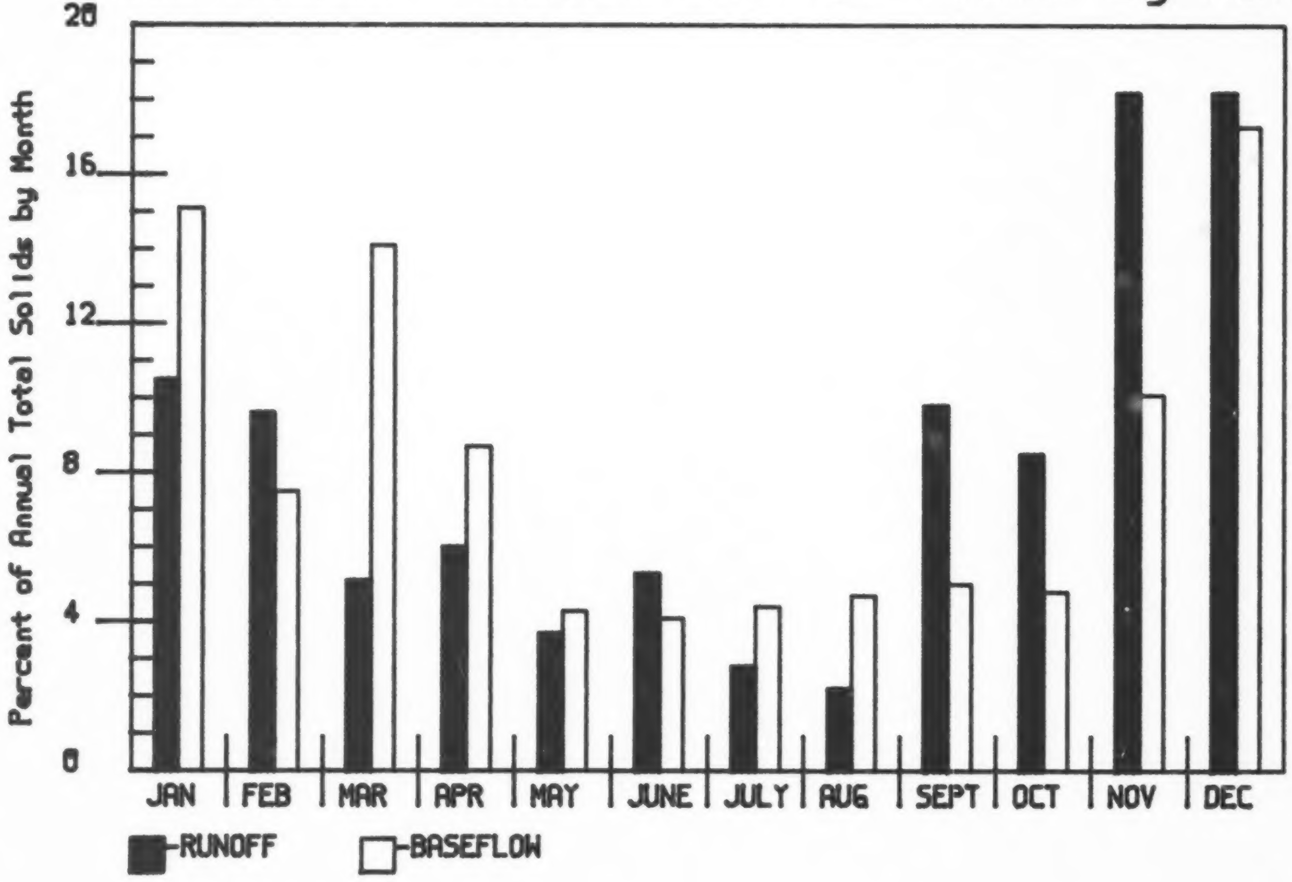

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FIGURE 6-4

SURREY DOWNS - Total Solids Yield by Month

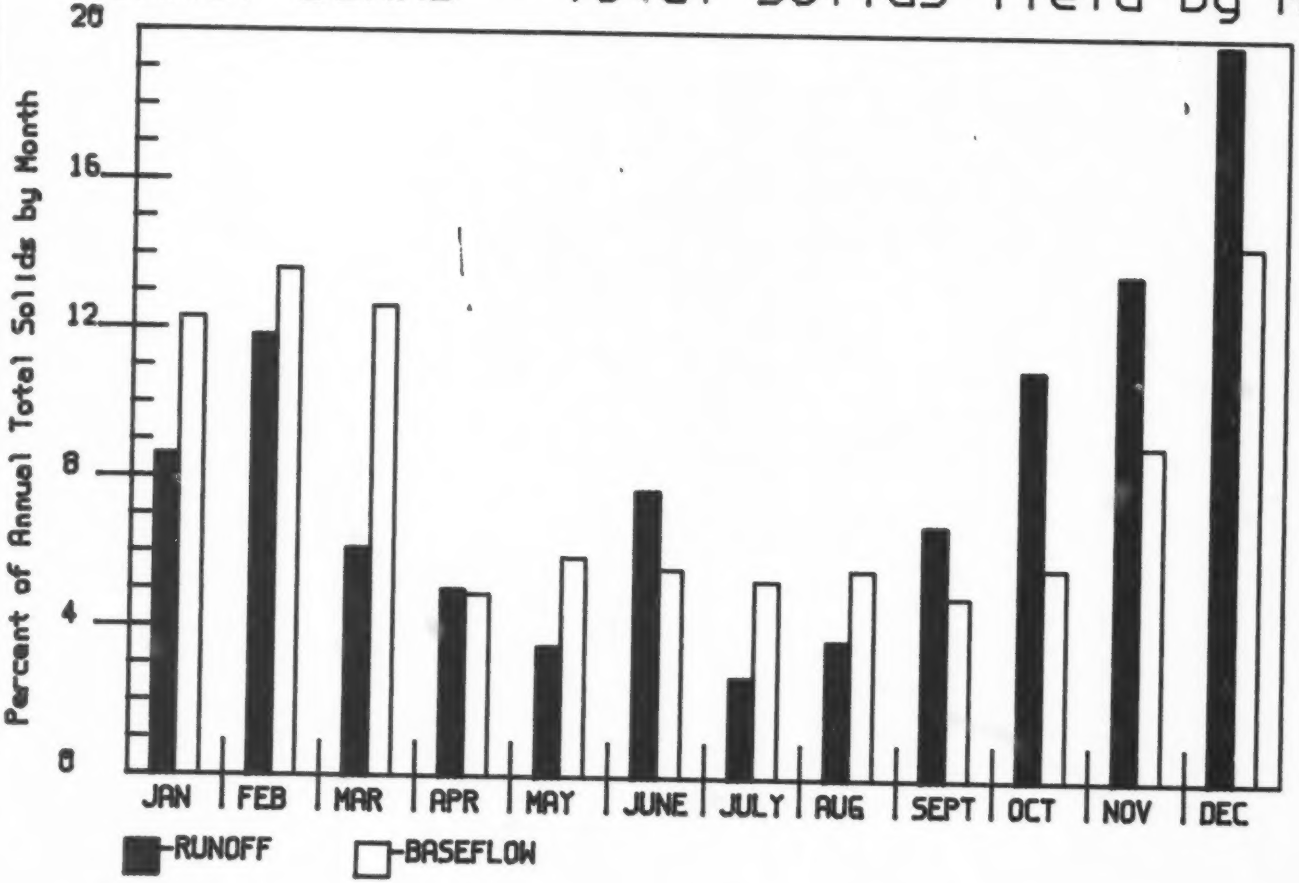

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FIGURE 6-5

LAKE HILLS - Total Solids by Season

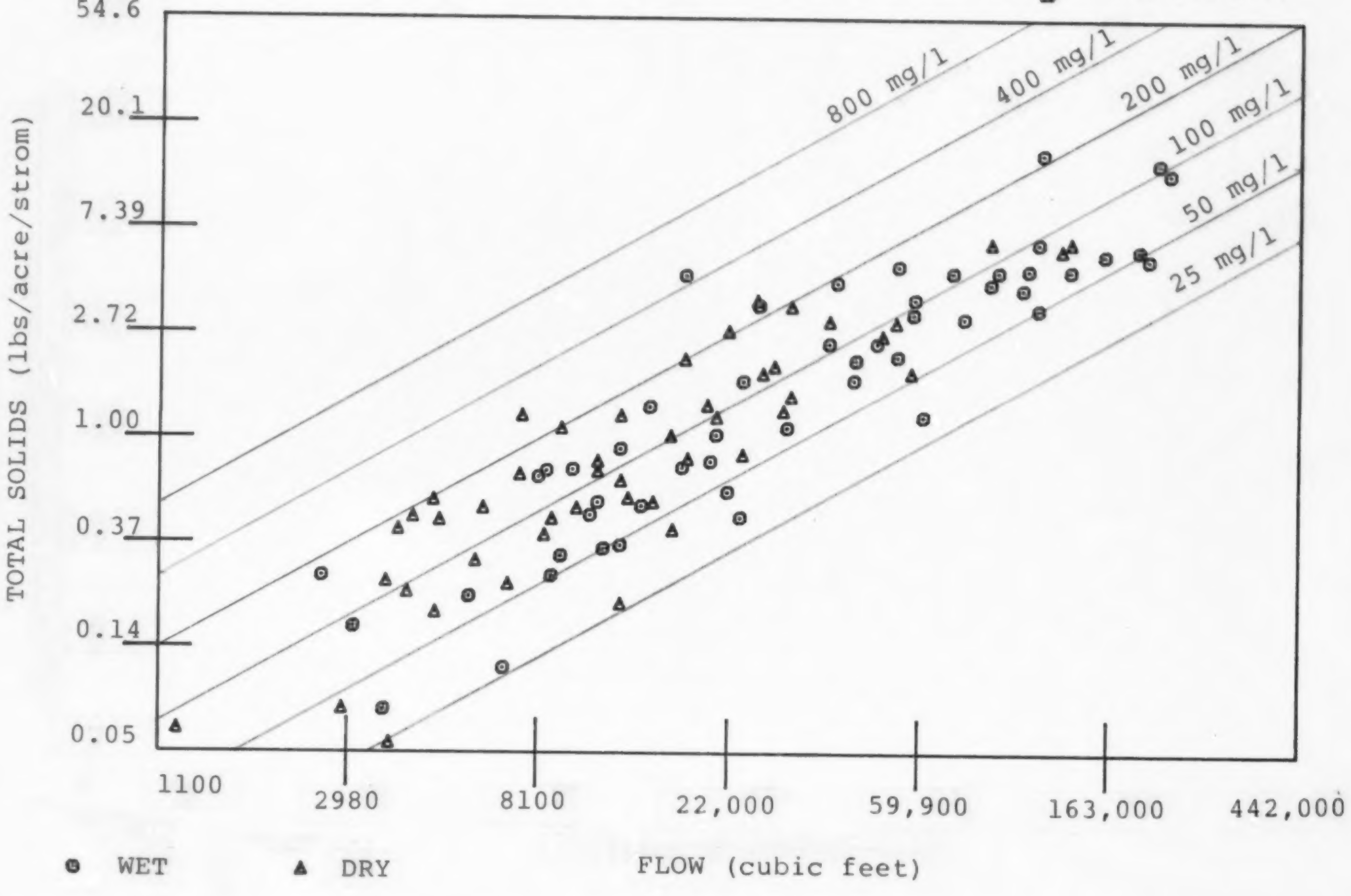

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FIGURE 6-6

SURREY DOWNS - Total Solids by Season

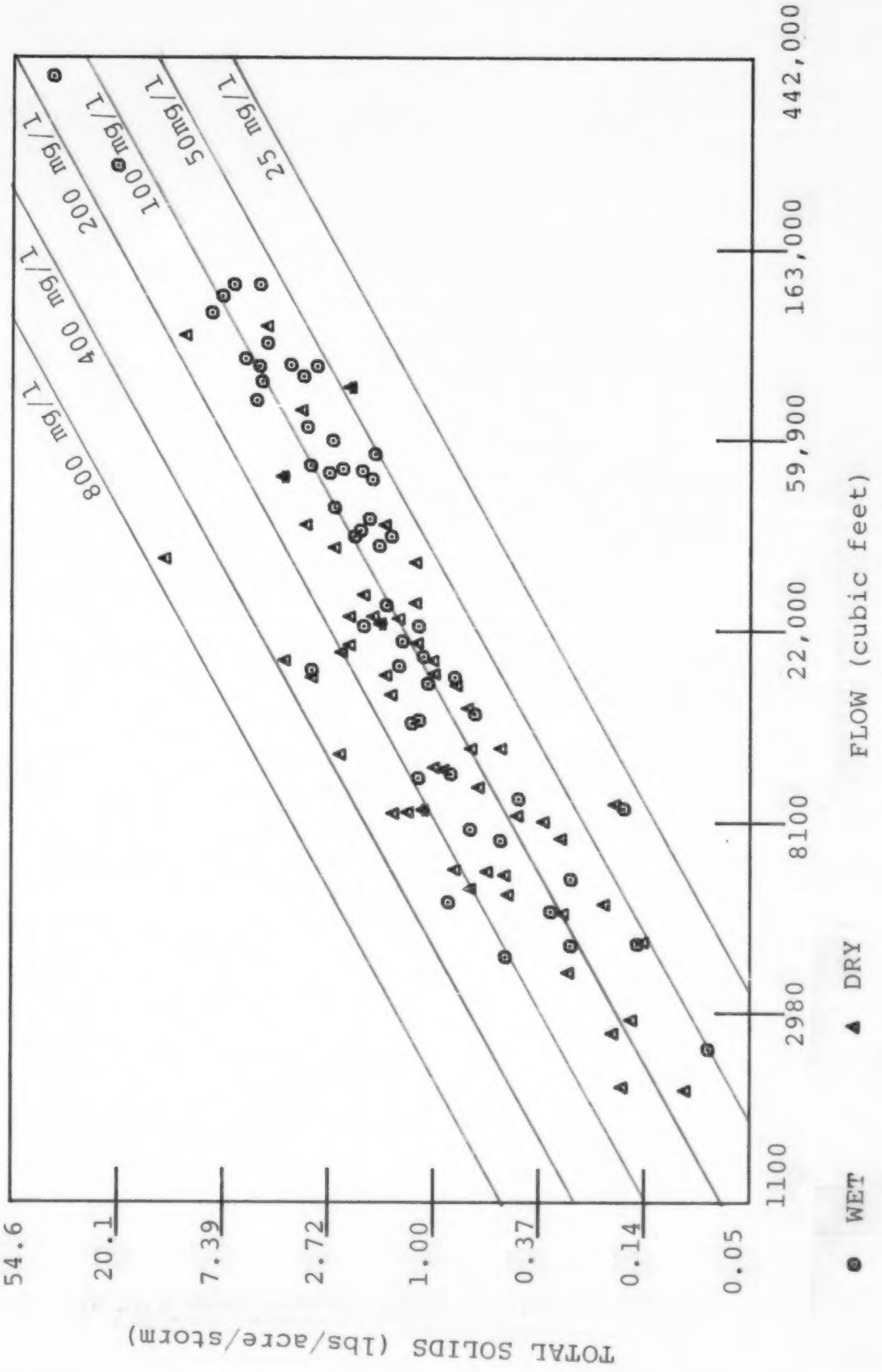

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FIGURE 6-7

LAKE HILLS - Lead by Season

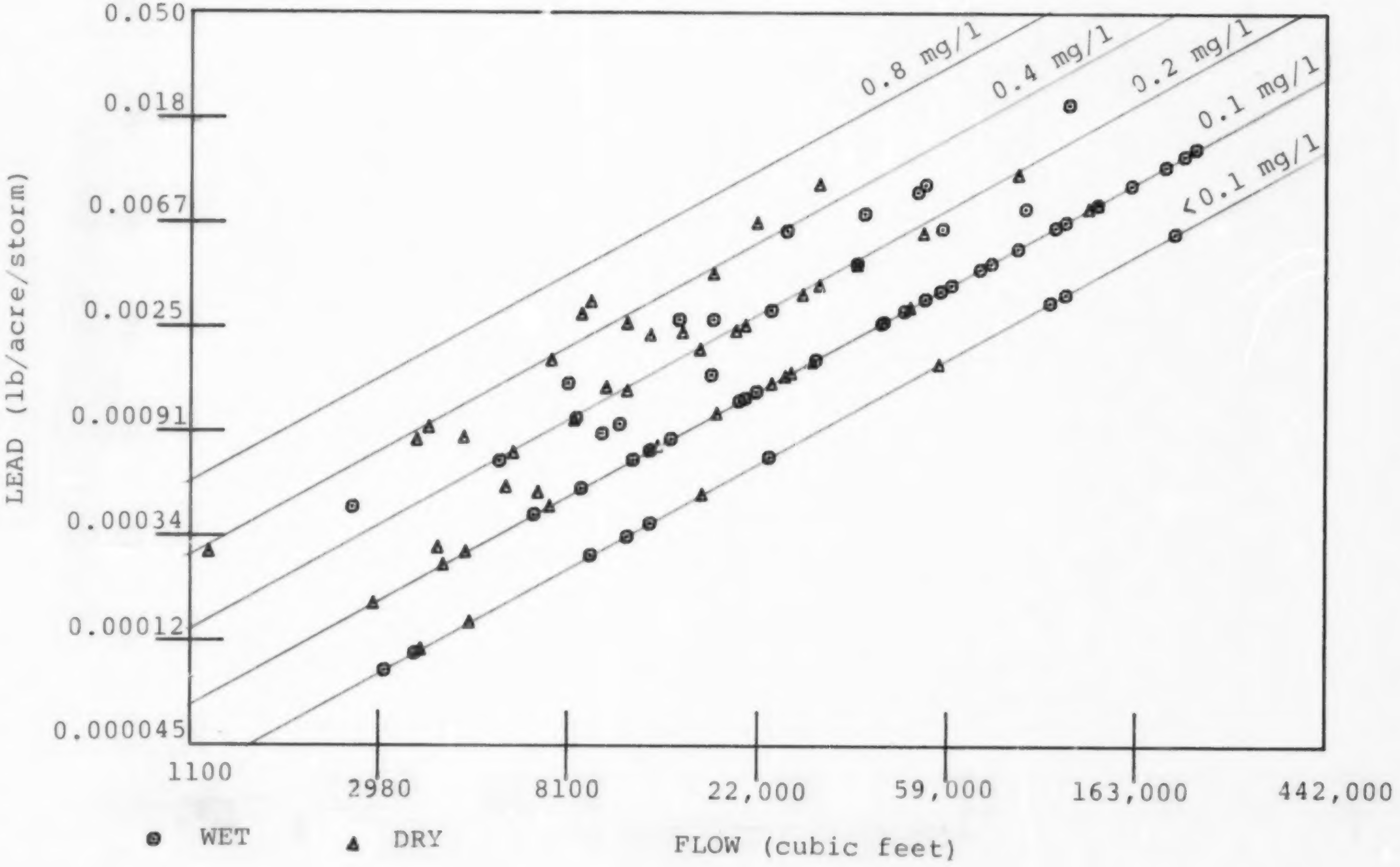
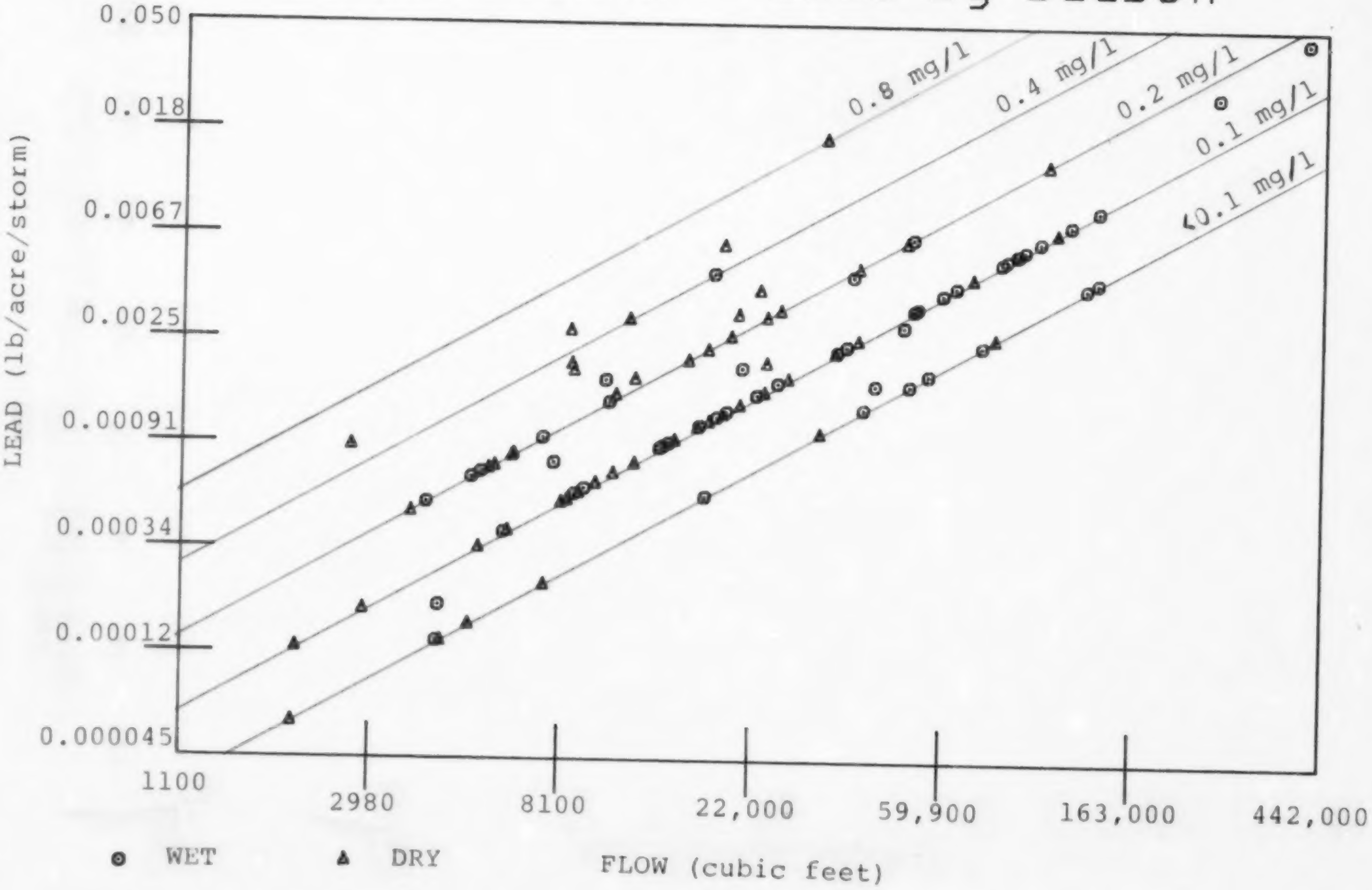


FIGURE 6-8

SURREY DOWNS - Lead by Season



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that required evenly distributed data. The data shown on these figures are separated by season, and bands of equal concentration values are drawn on these figures to indicate significant concentration shifts for different flow volumes. The total solids concentrations associated with the small events (of about 1,000 to 10,000 cubic feet, or 28,000 to 280,000 liters of flow) had concentrations of about 100 mg/l of total solids. When the runoff volumes increased substantially to about 100,000 cubic feet (2.8 million liters), the total solids concentrations decreased to about 75 mg/l. Again, these figures show the appreciable spread in observed concentrations for events in all flow categories. The lead data are much more grouped because of the high detection limit of the lead analysis procedure used. These data transformations are used in Section 9 to identify changes in runoff mass yields for the different pollutants as a function of season, runoff flow, and street cleaning program.

SOURCE AREA CONTRIBUTIONS OF URBAN RUNOFF POLLUTANTS

Determining the relative importance of different urban areas in contributing urban runoff pollutants must be based on an understanding of the natural and man-related processes and supplemented by limited data. It is very difficult to monitor individual source area components and attempt to make an urban runoff mass balance. This would require a very substantial monitoring effort over a fairly long period of time. Several types of each contributing source area must be monitored because of seemingly minor differences that can result in major differences in sheet flow runoff qualities. The previous discussion on urban runoff water sources from different source areas is extremely important in trying to determine sources of urban pollutants. Most of these source areas, however, are expected to have different pollutant strengths. Some urban sheet flow grab samples have been collected and analyzed for important urban runoff pollutants in San Jose, California (Pitt and Bozeman, 1982), Castro Valley, California (Pitt and Shawley, 1981), and in Ottawa, Ontario (Pitt, 1982). The site-specific urban runoff flow information previously described can also be used with local measurements of urban runoff particulate strengths and source area particulate strengths.

Urban runoff particulate strengths can be estimated by dividing the runoff constituent concentration by the associated total solids concentration. This results in a unit of milligrams of constituents per kilogram of total solids, or parts per million (when multiplied by 1000). These runoff relative concentrations can be compared to the concentrations found for source area particulates (such as street dirt, soils, drainage sediments, etc.). If the urban runoff relative strength is greater than for a specific source area particulate strength, then that source area is not an important contributor for that specific constituent. In other words, particulates from other source areas have stronger relative concentrations and/or are more effective in reaching the outfall. However, if a specific source area relative strength is greater than the urban runoff relative strength, then that source area is probably an important urban runoff pollutant source for that constituent.

The relative concentration of the urban runoff constituents can be calculated from the concentration data shown in Tables A-8 through A-15 of Appendix A. The resultant relative concentrations can be expressed as milligrams of constituent per kilogram of total solids, or parts per million. The runoff relative concentration values for Bellevue are surprisingly high, possibly because of the relatively low concentrations of total solids in the runoff. Much of the chemical oxygen demand and the nutrients are expected to be as soluble forms. These dissolved strengths are higher than the street dirt pollutant solids strengths discussed in Section 7. The total Kjeldahl nitrogen and zinc runoff pollutant strengths are five to ten times greater than the observed street dirt pollutant strengths while the total phosphorus pollutant strengths in the runoff are about three to five times the street dirt strengths. The chemical oxygen demand and lead strengths are about twice the street dirt strengths. The runoff concentrations and loadings observed for Bellevue are relatively low, but the street dirt strengths were about the same as compared to other locations studied. The higher particulate strengths in the runoff when compared with the street dirt pollutant strengths may indicate an accumulation of the larger, less polluted street dirt particulates in the storm drainage system.

Important sources of problem pollutants are related to various uses and processes. These include natural sources, such as rock weathering to produce soil, groundwater infiltration, volcanoes, and forest fires. Automobile use usually affects the road dust and dirt more than other particulate sources of street runoff. The road dust and dirt quality is affected by vehicle fluid drips and spills (such as gasoline and oils), gasoline combustion, and vehicle wear products. Local soil erosion and pavement wear products can also significantly contribute to street surface particulate loadings. Urban landscaping practices potentially affecting urban runoff include vegetation debris disposal and fertilizer and pesticide uses. Animal wastes also affect urban runoff quality. Other sources of urban runoff pollutants that may be important in specific cases include fireworks debris, wildlife, and sanitary wastewater infiltration. The quality of rain, snow, and atmospheric dust fallout are all affected by urban particulate resuspension after initial deposition. Many manufacturing and industrial activities also affect urban runoff quality, especially settleable air pollutants. Therefore, it is extremely difficult to identify a small number of activities that contribute most of the significant urban runoff pollutants.

Some relationships between sources and specific pollutants are evident. Natural weathering and erosion products of rocks probably contribute the majority of the hardness and iron in urban runoff. Road dust and associated automobile use activities contribute most of the lead in urban runoff. In certain situations, paint chips can also be a major source of lead. Urban landscaping activities can be a major source of cadmium. Electroplating and ore-processing activities may also contribute cadmium.

Many pollutant sources are also specific to a particular area and ongoing activities. Iron oxides, for example, are associated with welding operations and strontium, used in the production of flares and fireworks, would probably be found on the streets in greater quantities around holidays, and/or at the scenes of traffic accidents. The relative contribution of each of these potential urban runoff pollutant sources is therefore highly variable, depending on specific site conditions and seasons.

Tables 6-6 and 6-7 are qualitative summaries that show the types of urban runoff pollutants generally associated with different source areas. They indicate that no single area should be viewed as contributing the majority of any given type of pollutant, despite the fact that certain areas are consistently important sources of certain pollutants. For example, street surfaces are consistently shown to be responsible for significant contributions of many heavy metals. Similarly, oxygen demanding materials and nutrients are shown to originate mostly from landscaped and vacant areas. Table 6-6 defines the urban runoff pollutants in terms of general classes of water quality parameters (e.g., nutrients, bacteria, and heavy metals). Table 6-7 is similar but defines the urban runoff pollutants in terms of various common materials (e.g., auto exhaust, litter, and feces).

An important information need for urban runoff sources studies is knowing the relative contributions from different pollutant sources in the watershed to the outfall yield. Sources that are far from the storm drainage system and require considerable overland flow have a very low yield of most pollutants when compared with parking lots or street surfaces which are impervious and located adjacent to the drainage system (hydraulically connected). Those areas that are further away from the drainage system may require directed or sheet flows of the runoff to pass over pervious areas. This increases the infiltration of the polluted waters into the soils and enhances their uptake by vegetation along the drainage routes. Barriers can also cause ponding and settling of polluted sediments from the runoff. All of these factors significantly act to prevent the contaminated particulates from reaching the receiving waters. However, during large storms, especially when the ground is saturated, the erosion of these now contaminated soils may significantly degrade urban runoff quality. In addition, the resuspended contaminated street surface particulates (by wind and automobile induced turbulence) can be redeposited in adjacent non-paved areas. These street surface particulates that contaminate the nearby soils reduce the quantity of street surface particulates directly affecting the receiving waters. These redeposited street surface particulates can then be washed into the receiving waters during periods of high erosion.

As mentioned previously, some urban runoff sheet flow samples have been collected and analyzed in other areas. Sheet flow samples during several rain events were collected from small watershed areas such as building roofs, parking lots, vacant lots, and gutters. Rainfall samples were also collected in many cases. Table 6-8 shows the relative concentrations of pollutants in source area runoff in San Jose as summarized by Pitt and Bozeman (1982). Rainwater was found in most cases to have the lowest pollutant concentrations while parking lot and gutter flow samples had the highest concentrations. Puddles in a park area were also sampled and found to have higher specific conductance values and concentrations of total solids and nitrates than other samples.

More recent sampling in Ottawa, Ontario (Pitt, 1982), indicated that almost all of the lead in urban runoff originated from parking lots and

Table 6-6 SOURCES OF URBAN RUNOFF POLLUTANTS

	Rooftops	Street Surfaces	Parking Lots	Landscaped Areas	Vacant Land	Construction Sites
Sediment		X	X	X	X	X
Oxygen Demanding Matter				X		
Nutrients				X	X	
Bacteria		X			X	
Heavy Metals	X	X	X			
Pesticides & Herbicides				X		
Oils and grease		X	X			X
Floating matter				X		
Other toxic materials	X	X	X			X

Source: from Pitt and Bozeman, 1982

Table 6-7. SOURCES OF MATERIALS WHICH LEAD TO URBAN RUNOFF POLLUTION

	Lawn and Landscaped Areas	Vacant Lots	Rooftops	Sidewalks	Parking Lots	Street Surfaces
Dustfall	X	X	X	X	X	X
Precipitation	X	X	X	X	X	X
Tire Wear	X			X	X	X
Auto Exhaust Particulates	X			X	X	X
Other Auto Use (Fluid Drips, Wear Prod.)					X	X
Vegetation Litter	X	X		X	X	X
Construction Erosion		X				
Other Litter		X		X	X	X
Bird Feces	X	X	X	X		
Dog Feces	X	X		X	X	X
Cat Feces	X	X				
Fertilizer Use	X					
Pesticide Use	X					

Source: from Pitt and Bozeman, 1982

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Table 6-8. Relative Concentrations of Pollutants in Runoff from Major Areas (1)

Constituent	Parking Lots, Driveways, and Streets	Residential Roofs	Landscaped Areas
pH	1.1	1.0	1.1
Spec. Cond.	4.0	1.0	220
Turbidity	300	<1	23
Total Solids	21	1.0	130
COD	9.0	1.0	3.5
Total Phosphate	4.7	1.0	4.0
TKN	2.0	1.0	1.8
Lead	70	1.0	2.0
Zinc	19	15	1.0

(1) The lowest reported concentration of a specific constituent is arbitrarily assigned 1.0. The other source values are multiples of this lowest value.

Source: from Pitt and Bozeman, 1982.

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street surfaces with very little lead found in runoff from rooftops, vacant and landscaped areas, and unpaved parking lots. The relative pollutant concentrations shown in Table 6-8 were combined with the relative flow contributions as shown in Figures 5-5 through 5-8 in Section 5. Estimates of the importance of various source areas were made and are shown as Figures 6-9 through 6-14. These figures are only estimates due to the lack of site specific source concentration data. However, they are accurate enough to indicate the relative importance of the different source areas and how their relative importance changes for different rain conditions. Figure 6-9 shows that street surfaces contribute very small amounts of the runoff total solids particulates for rains greater than 0.1 inch (2.5 mm). The major sources of total solids for almost all rains in Bellevue are expected to be the landscaped front and back yards. Figure 6-10 shows that street surfaces contribute important fractions of the urban runoff COD for almost all rains. Driveways and parking lots also may contribute important quantities of COD. The previous areas surprisingly contribute relatively small fractions of the expected urban runoff COD. The relative contributions of phosphates and total Kjeldahl nitrogen as shown in Figures 6-11 and 6-12 are, as expected, similar. However, streets may contribute important amounts of these nutrients, especially for the smaller rains, because during the smaller rains, street surfaces contribute almost all of the runoff flows. Pervious and impervious source areas contribute about equal amounts of the nutrients for most of the rains. As expected, lead, as shown in Figure 6-13, is mostly contributed by street surfaces for all rains. Driveways and parking lots supply almost all of the rest of the lead in urban runoff. Zinc is also contributed mostly by street surfaces, driveways, and parking lots; but, for some reason, high rooftop zinc concentrations have been noted.

Rainfall is typically less effective in removing materials from rough pavement (e.g., streets surfaced with oil and screens or streets in poor condition) than from smooth pavement (e.g., asphalt streets in good condition). It is thought that the increased roughness mechanically traps particulate matter and also reduces scour velocities at the pavement/water interface. These mechanisms have the effect of preventing some of the materials which have eroded from surrounding areas from reaching the storm drainage system.

The amount and character of runoff pollutants from a given site depend on factors such as the intensity and duration of the storm event and the length of the antecedent dry period (i.e., the period of pollutant accumulation). Large storms (ones with high intensities and/or large rainfall volumes) result in small contributions of the street surface particulates, relative to the total runoff particulate yield. This pattern is more pronounced when the antecedent dry periods are short. During such conditions, the street surfaces stay relatively clean (because of the frequent rains). A large rain will result in significant erosion from the surrounding saturated pervious areas, so that eroded materials become deposited on the streets after the storm's end. It is expected that areas with moderate rainfall intensities and long periods of accumulation (i.e., dirty street surfaces and dry surrounding soil conditions) would have most of their urban runoff output associated with street surface washoff.

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FIGURE 6-9

URBAN RUNOFF SOURCES FOR TOTAL SOLIDS

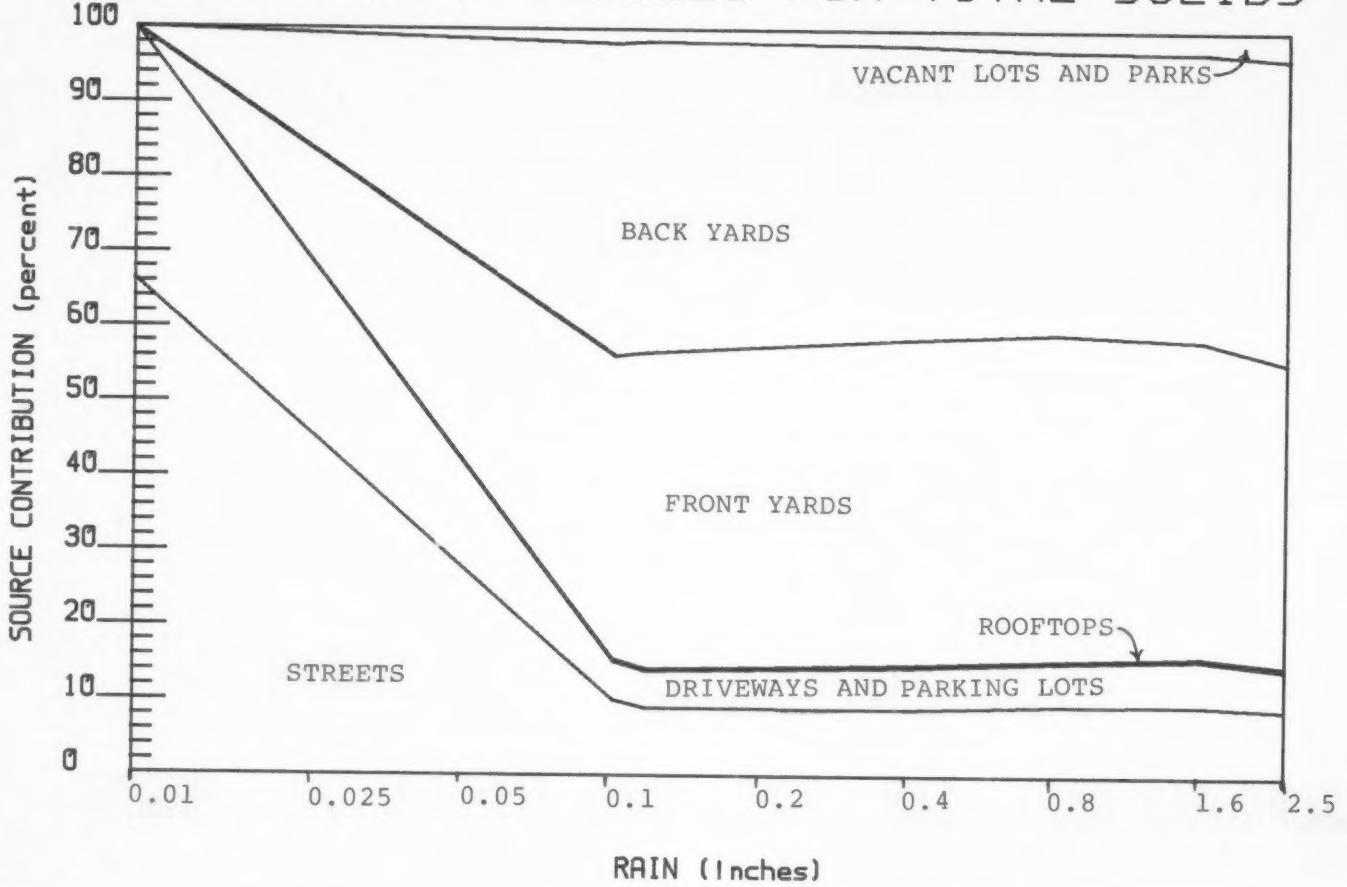

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FIGURE 6-10

URBAN RUNOFF SOURCES FOR COD

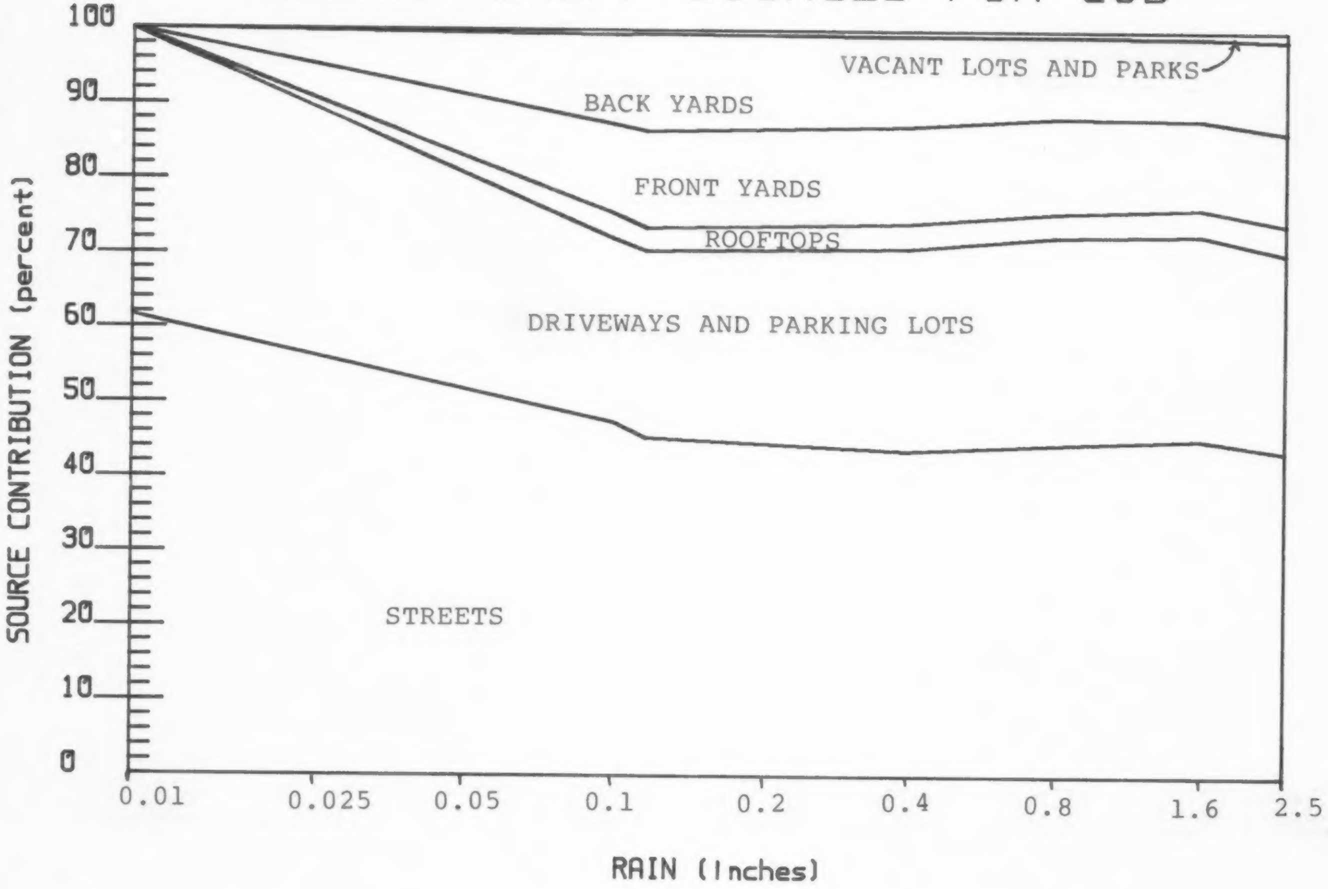

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FIGURE 6-11

URBAN RUNOFF SOURCES FOR PHOSPHATES

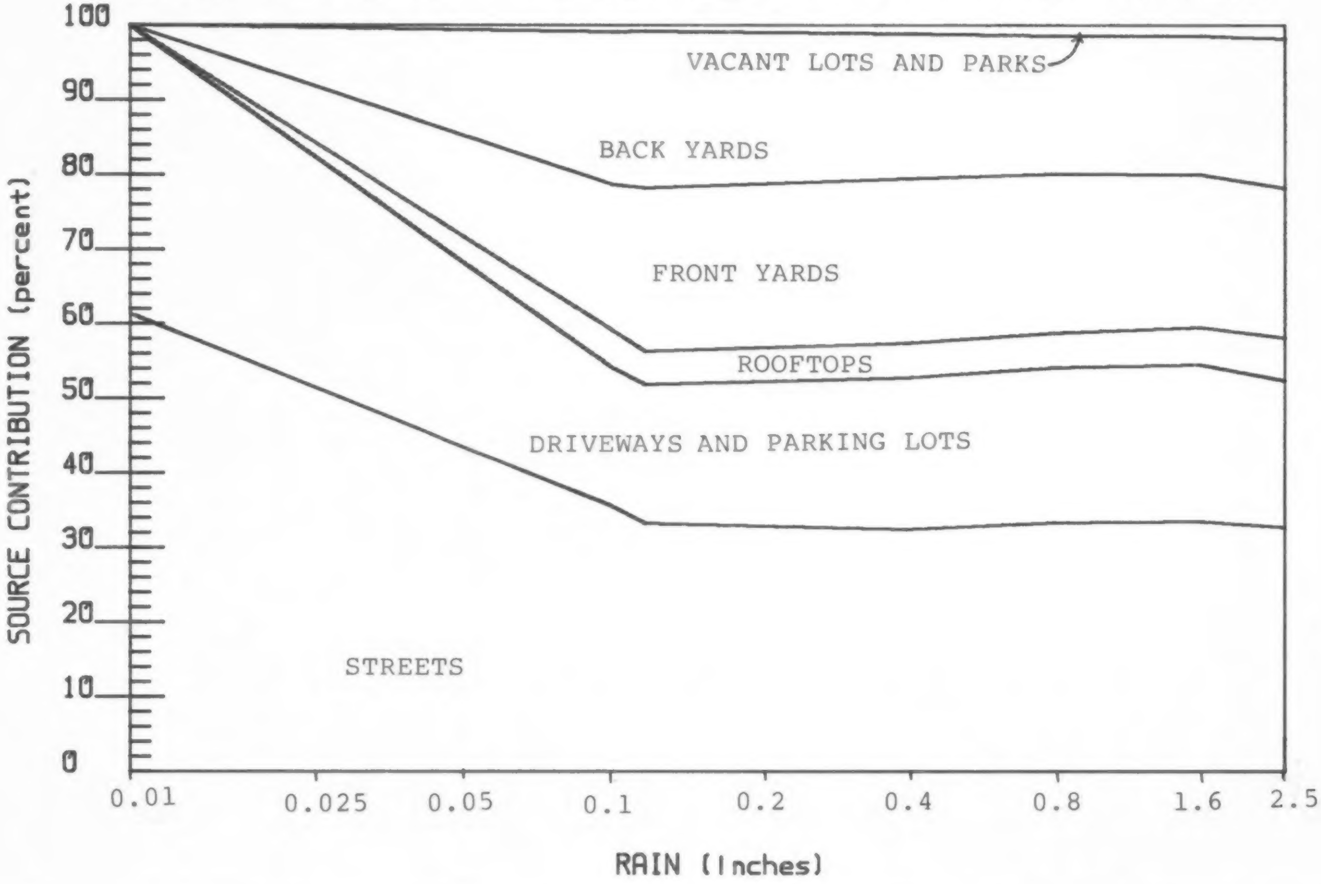

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FIGURE 6-12

URBAN RUNOFF SOURCES FOR TKN

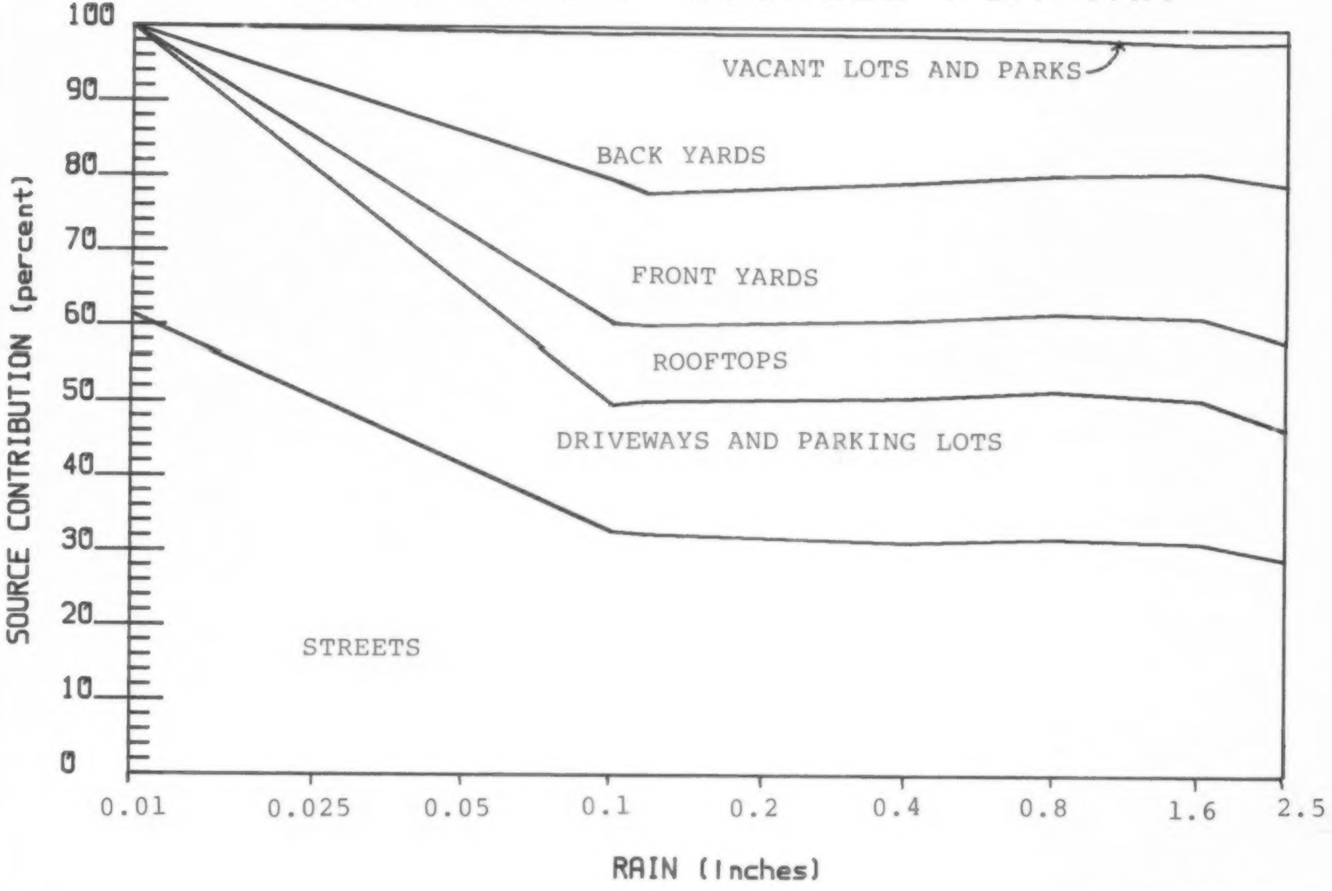

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FIGURE 6-13

URBAN RUNOFF SOURCES FOR LEAD

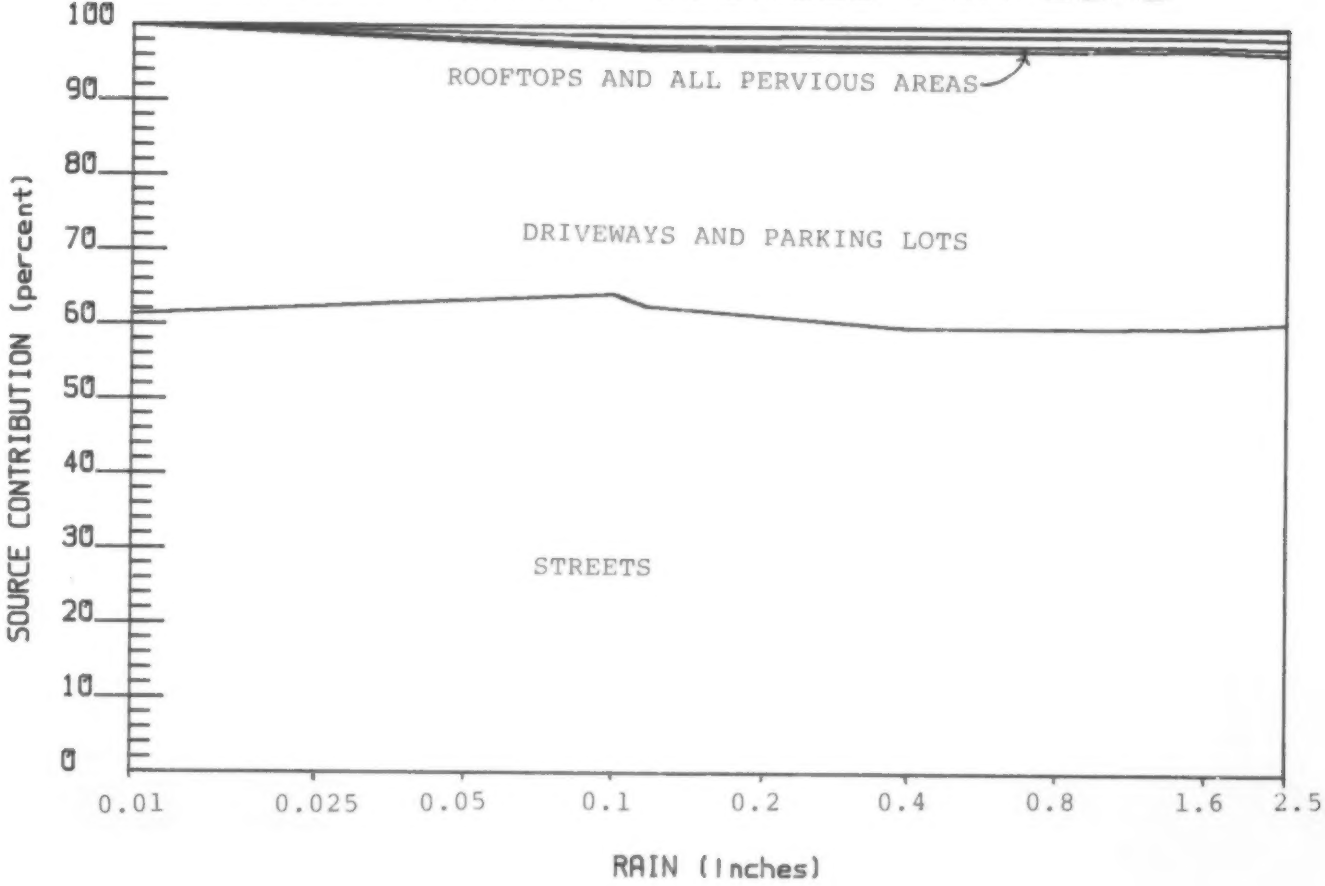

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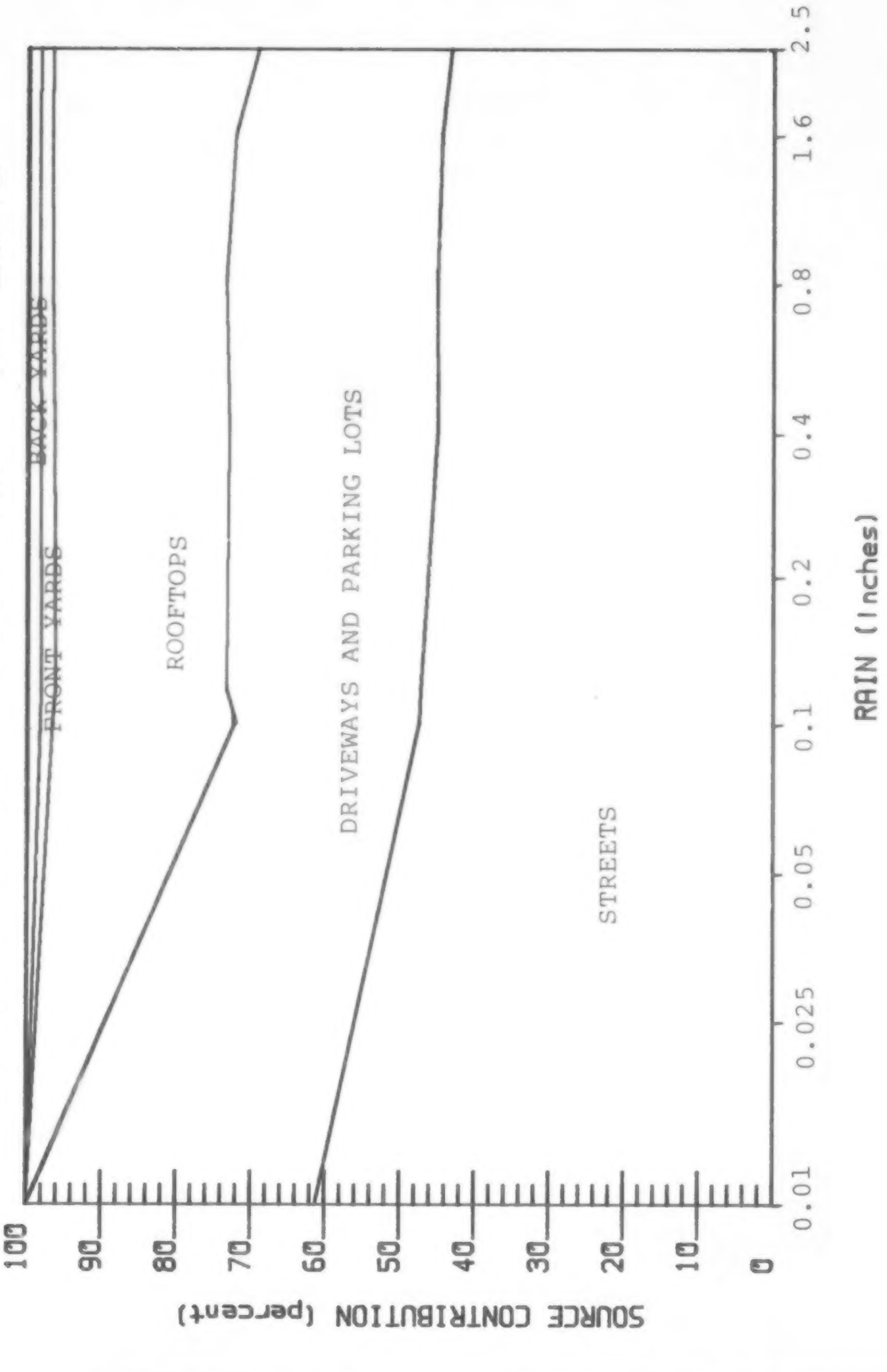
FIGURE 6-14

URBAN RUNOFF SOURCES FOR ZINC



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During storms of moderate to low intensity, the amount of traffic has been found to have an important influence on the degree to which pollutants will be transported into the storm sewerage system. Traffic can supply some of the energy needed at the street surface to loosen particulates by increasing the scour and shear velocities at the water/street interface). When light storms occur at night (or at other times of low traffic), very little street dirt would be loosened, and there would be little opportunity for it to be transported along the street and gutter system. In summary, estimated yields from different source areas in a watershed are very site and time dependent (it is necessary to consider pavement characteristics, antecedent weather conditions, current storm characteristics, and traffic conditions).

Appendix G includes a more detailed discussion of the sources of urban runoff pollutants, based upon studies conducted from many locations throughout the country. Appendix G also describes the chemical quality of soils in urban areas, the mechanisms of automobile use that contribute heavy metals, the role of landscaping activities in urban areas that contribute runoff pollutants, and the internal cycling of various pollutants in an urban area due to atmospheric resuspension of urban dusts with subsequent particulate redeposition. Appendix H reviews the reactions and fates of important urban runoff pollutants, also based upon literature information. This appendix discusses the chemical reactions of urban runoff pollutants after they enter receiving waters, especially the redox reactions. Absorption and ion exchange are also discussed.

SECTION 7
STREET DIRT CHARACTERISTICS

This section discusses characteristics of street surface particulates. The topics considered are factors affecting street cleanliness, street surface particulate accumulation and deposition rates, the distribution of street dirt in driving and parking lanes, and the chemical strengths of street surface particulates. The Bellevue street particulate characterization information was also compared to similar characteristics determined for other areas. The unique Bellevue climatic conditions, as described previously in Section 4 affect certain street surface particulate characteristics.

FACTORS AFFECTING STREET CLEANLINESS

Appendix E describes the experimental design sampling that was conducted as part of the Bellevue tests. The experimental design street surface particulate samples were collected from about 20 to 50 locations throughout each of the three Surrey Downs sub-areas and the Lake Hills and 148th Avenue areas. These samples were collected about every six months and were designed to measure the street surface particulate loading variabilities that occurred in each of these areas as a function of season. Appendix E also describes how the street surface sampling effort was modified periodically to reflect the changes in variabilities that were noted.

Each of the many samples in each test area were accompanied by complete sampling area descriptions. The most important information noted related to street condition, traffic density, topography, and land-use. The season of the year was also noted. This data was used to identify the characteristics most important to determining street surface loading values. Each series of experimental design samples were collected within one or two days and had similar accumulation periods. In some cases, data were not used in this analysis because the experimental design sample collection effort was interrupted by rains. Because each experimental design sample location was the same for each of the sampling periods, a paired Student's "T" test was used to identify significant differences in observed loadings due to season only. A paired "T" test was used because the street condition, street density, topography, and land-use would not change for the same location at different times during the two years. There were three sample sets in Surrey Downs: April and November of 1980 and July of 1981. The April and July sampling times were conducted during dry seasons while the November sampling effort was conducted during a wet season. When the April and July samples were compared using a paired "T" test, no significant difference in sample loadings were observed. However, when the November sample data were compared to both the April and July data independently, the loadings were significantly different at greater than a 95 percent level. The average Surrey Downs loadings in April and July were about 400 lbs/curb-mile (110 g/curb-meter) in November.

Similar analyses were conducted during two sampling periods for Lake Hills. An October, 1980, sample series was compared with a July, 1981, sample series using a paired Student's "T" test. For these Lake Hills tests, no significant difference was found between these wet and dry season dates. The average street surface loading values were about 220 lbs/curb-mile (62 g/curb-meter).

Samples from two test dates (April, 1980, and July, 1981) were available for the 108th Street sub-area in Surrey Downs. The paired "T" tests for these two dry season samples again showed no significant difference. The average loadings in this sub-area were about 400 lbs/curb-mile (110 g/curb-meter). Only one set of experimental design samples were available for the Westwood Homes Road sub-area in Surrey Downs (April, 1980). The average loading values were about 2,000 lbs/curb-mile (570 g/curb-meter). There was also a single set of experimental design samples available for 148th Avenue (March, 1981). These samples resulted in an average street surface loading value of about 1,000 lbs/curb-mile (280 g/curb-meter). These experimental design data pointed out the need to separate the Surrey Downs area into subsections, especially considering that Westwood Home Road and 108th Street did not have curbs and could not be cleaned by the city street cleaning equipment.

Using a nonpaired Student's "T" test, dry season samples collected in Surrey Downs were compared with dry season samples collected at 108th Avenue, for Westwood Homes Road and in Lake Hills. There was no significant differences found for the Surrey Downs and 108th Street samples. However, very significant differences were detected between the Surrey Downs and The Westwood Homes Road samples and the 108th Street and the Westwood Homes Road samples. The July 1981 samples for Surrey Downs and 108th Street were also compared and were not significantly different.

Additional Student's "T" tests were conducted by grouping the experimental design data into categories corresponding to different street conditions, topography, and season. In some cases, there was disagreement in the street condition and topography at the same sites during the different sampling periods. This data was therefore eliminated from the analyses. The major difference observed in Lake Hills was for topography, where levels of significance greater than 95 percent were observed in both the July and October sampling periods. Flat areas during both sampling periods had average loads of about 240 lbs/curb-mile (68 g/curb-meter) while the area in Lake Hills with some slope averaged about 140 lbs/curb-mile (40 g/curb-meter). As noted previously, there were major seasonal differences observed in Surrey Downs, but not in Lake Hills. There were no significant differences observed in Lake Hills based upon the differences in street conditions, probably because of the narrow range in street surface conditions that existed within the study areas.

Differences in street loadings on 148th Avenue due to street slope were marginally significant at the 80 percent level. Flat stretches of 148th Avenue had street surface loadings of about 1,000 lbs/curb-mile (280 g/curb-meter). It would be expected that steeper slopes would result in lower street surface loadings, such as occurred in Lake Hills.

Because of the results of the Student's "T" tests, further statistical tests using factorial analyses were conducted on the experimental design data. A two-level, three-way factorial analysis was conducted on both the Lake Hills and Surrey Downs experimental design data. The three factors considered were street condition, topography, and season. The two levels were coded for fair or poor versus good street surface conditions; flat streets versus streets with greater slopes; and dry versus wet seasons. The data was coded using plus one values for those conditions expected to increase street surface loadings (fair or poor street surface conditions, flat topography, and dry seasons). The other level for each condition was assigned a minus one coding value corresponding to expected decreases in resultant loading values. Again, data with conflicting coding values on the data sheets were eliminated from this analysis. A total of eight different possibilities can occur for these three factors. From two to seventeen observations were available for each of these eight factors for the Lake Hills data. Many more data were available for the Surrey Downs test site.

Figures 7-1 and 7-2 show the results of these factorial analyses. Figure 7-1 shows the resultant calculated effects on probability paper for these three main factors and their interactions. Those main effects and interactions corresponding to a straight line on the probability paper may occur randomly and are, therefore, not important effects. Major effects or interactions that do not fall on the straight lines are significantly different and are not likely to occur due to random conditions. In Lake Hills, the only significant effect observed was associated with season. The resultant model shows that loadings during the wet seasons are expected to be about 145 lbs/curb-mile (41 g/curb-meter), while the loadings could increase to about 235 lbs/curb-mile (67 g/curb-meter) during the dry season. This confirms the Student's "T" test observations by indicating the overall importance of seasonal effects on the Lake Hills data.

The Surrey Downs data is also shown on Figure 7-1 and does not indicate a single overriding effect. The differences in loadings observed in Surrey Downs were associated with the interactions between all three effects. The expected Surrey Downs loadings could range from a low of about 170 lbs/curb-mile (48 g/curb-meter) for a negative three-way interaction code value to a high of about 460 lbs/curb-mile (130 g/curb-meter) for a resultant positive three-way interaction code value. A negative three-way coding value would occur when any one of the effects are negative and the other is positive, or if all three effects are negative. The three-way interaction would be positive if any one of the three conditions is positive, with the other two being negative, or if all three are positive. This is obviously a confusing interaction and shows the importance of obtaining as much information as possible during a set of field studies.

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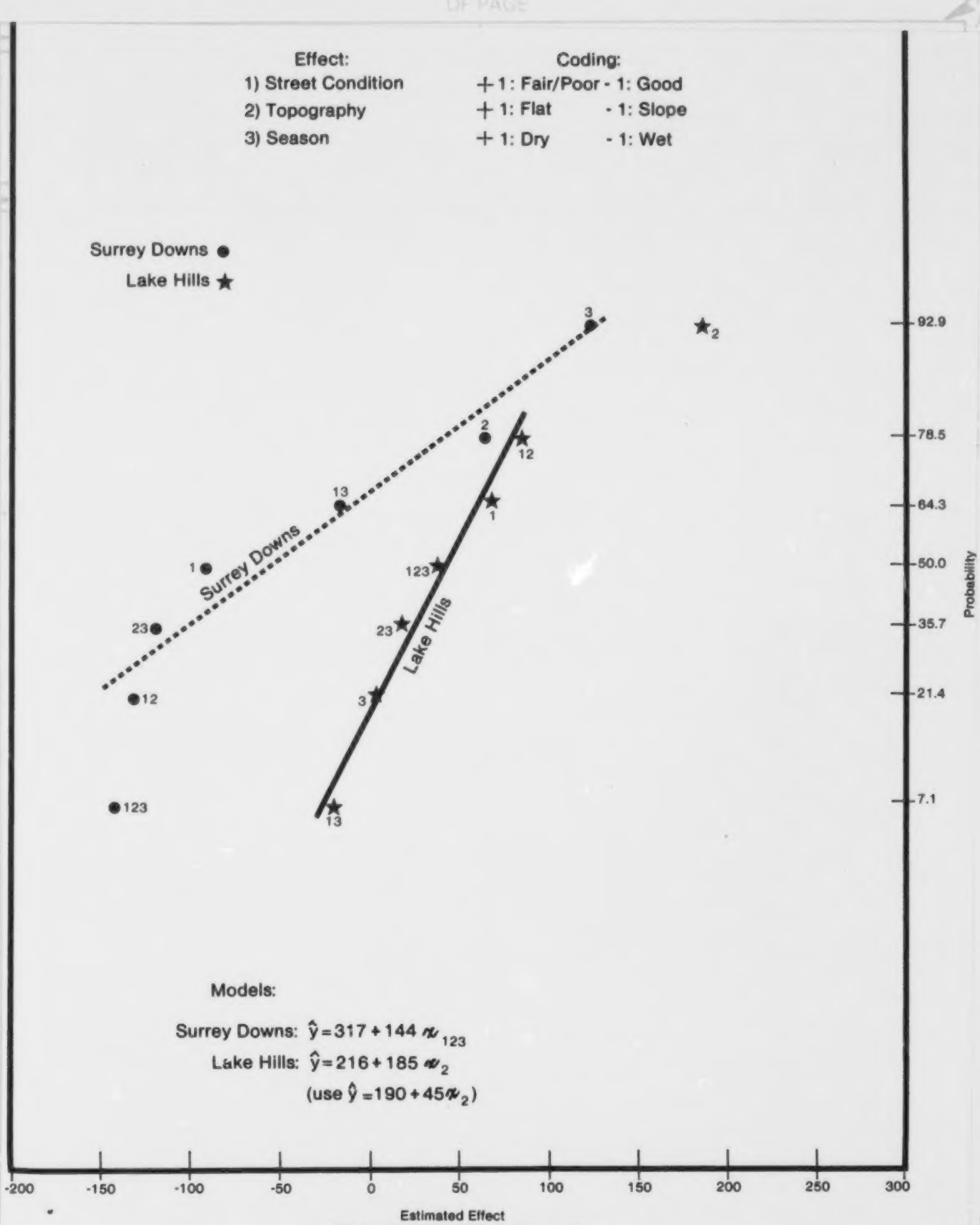

2^3 Factorial Analysis Results
for Experimental Design Street Particulate Loading Data

FIGURE 7-1

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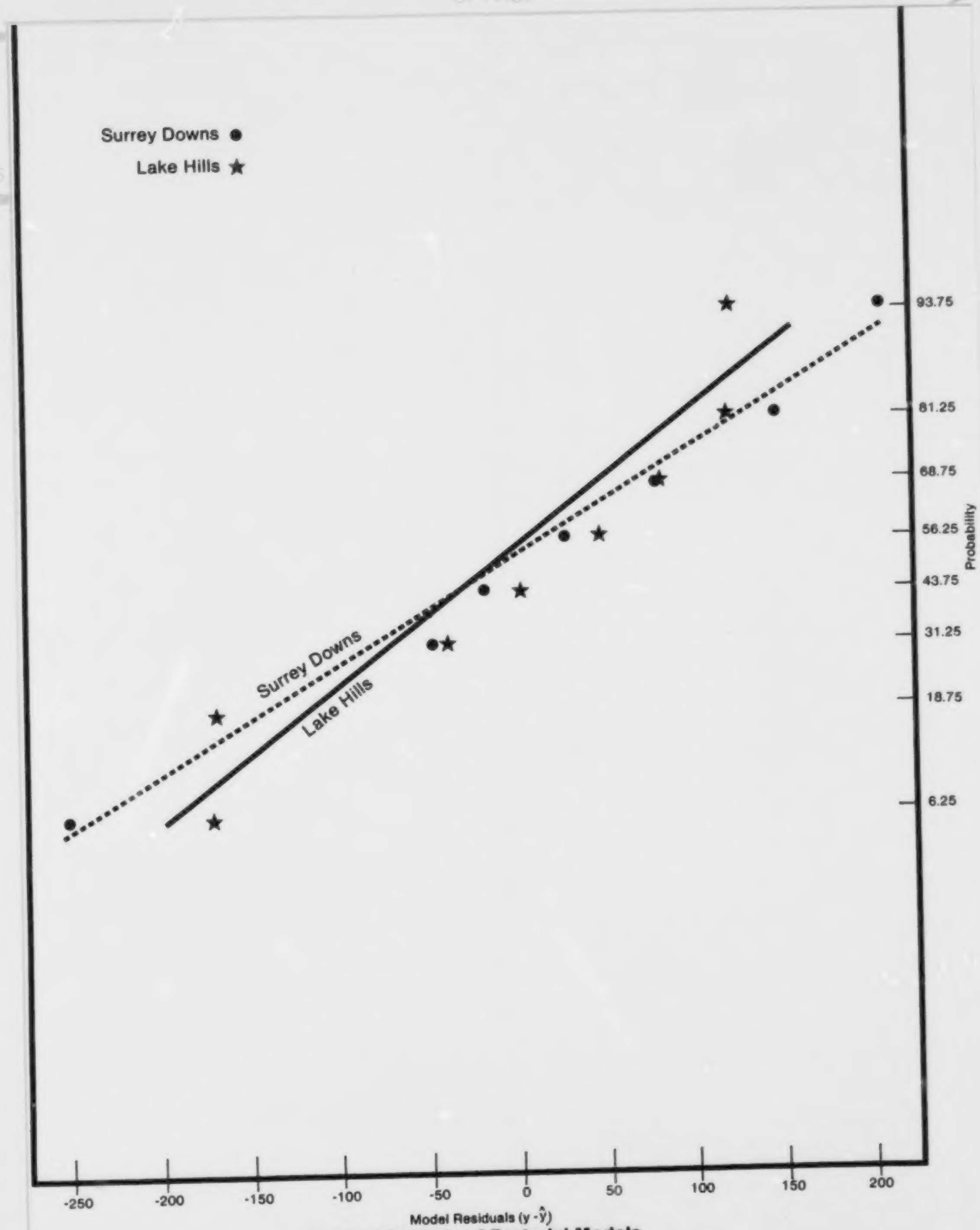

Residual Analysis of Factorial Models for Experimental Design Street Particulate Loadings

FIGURE 7-2

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Figure 7-2 is a probability plot of the residual values using these models. The calculated residuals for each of the eight possible combinations of main effects and interactions can be fitted to straight lines, within reason. The residuals (deviations from the calculated results using the model) are therefore random and are not expected to be associated with any other effects, except those shown to be important using the factorial analysis.

These results are site specific and are probably different not only for other cities but also for other locations in the same city. As noted, street surface conditions did not appear to be a major consideration in determining the street surface loadings in any one of the Bellevue sites, because the range in street surface conditions was not very great. A similar factorial analysis was conducted using the Castro Valley, California, street surface loading particulate data collected in 1978 and 1979 (Pitt and Shawley, 1981). The Castro Valley study area had a much greater range in street surface conditions than the Bellevue study sites. A five-way, two-level interaction examined with the Castro Valley data included street condition (fair or poor versus good), traffic density (moderate or heavy versus light), land-use (residential or vacant lots versus commercial or school), topography (flat versus moderate or steep slopes), and season (summer versus winter). Again, the data was coded with positive values for variable levels probably associated with increasing street dirt loadings. Instead of the eight possibilities associated with the tests conducted with the Bellevue data, 32 possibilities were associated with the Castro Valley data. Each of the 32 data sets had one to twenty-two data points. The seasonal effect was found to be very large in relationship to the other effects. The next most important effect was street condition, followed by a random occurrence of the other effects. The data was then separated into the two different seasons and further factorial analyses were conducted. During the winter conditions, the three-factor interaction of street condition, traffic density, and topography was the only important factor. During the summer, however, street condition was the only important factor. During the winter season, the expected street surface loadings would vary from about 600 to about 700 lbs/curb-mile (170 to 200 g/curb-meter) depending upon the three-way interaction described. During the summer, however, the street surface particulate loadings could be much greater, ranging from a low of about 1,400 lbs/curb-mile (400 g/curb-meter) to a high of about 2,800 lbs/curb-mile (800 g/curb-meter), depending upon the street surface condition. The three-factor interaction during the winter caused a relatively small change in the expected loading value, while the street condition contributed a much greater change in the expected loading value during the summer months.

STREET SURFACE PARTICULATE ACCUMULATION AND DEPOSITION RATES

A major element of the Bellevue urban runoff project involved collecting street surface samples to compare with the monitored storm runoff yields and to determine street cleaner performance. Another important use of this information was to estimate the deposition and accumulation rates for the various street surface contaminants.

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By the middle of January, 1982, about 600 good street surface accumulation samples were collected from five test areas (198 in the Surrey Downs cleaning area, 104 on 108th Ave, 52 on Westwood Home Road, 28 on 148th Avenue S.E., and 220 in the Lake Hills area).

In Appendix B, Tables B-1 through B-13 present the loading values for these 600 street surface particulate samples. These tables show the date of sample collection, the sample identification number, the days from the last significant rainfall and the number of days from the last street cleaning. The observed total solids street surface loading values are shown along with the calculated median particle sizes using procedures described in Appendices E and F. The data from these particle size analyses were used to calculate the median particle size. These tables also include the street cleaning effectiveness data (loadings on the street before and after street cleaning) that will be discussed in Section 10. These tables divide the data into the five test areas and by season. The Surrey Downs and Lake Hills data are also divided into categories associated with periods of intensive street cleaning and periods of no street cleaning.

Each street surface sample is identified with a specific accumulation period. This accumulation period is the time since that test area was last cleaned with mechanical street cleaning equipment or the time since a significant rain washed the area. A significant rain is defined as a rain capable of washing most of the available street dirt from the street surfaces. Based on the rainfall and washoff analyses from this and past street dirt collection projects, a significant rain is estimated to be one with a total of about 0.2 inches (5 mm) or more of rain falling within several hours (irrespective of traffic conditions), rain with a peak instantaneous five-minute intensity of at least 0.5 inches (13 mm) per hour (also irrespective of traffic conditions), or a rain with an average intensity of 0.1 inches (2.5 mm) or greater per hour with moderate to heavy traffic. Rains and traffic conditions which meet one of these criteria are capable of imparting enough energy to the street surface to loosen the available contaminants and to supply sufficient water to flush them along the street surface and gutters and on to the storm sewerage inlets. If sufficient runoff is not available to carry the particulates through the storm sewerage to the outfall, material will be deposited in the sewerage system.

The observed street surface particulate loading values for each sample were plotted to observe changes in loadings with time and to determine the initial deposition and long-term accumulation rates. The deposition rate is the initial accumulation rate which occurs over the first several days. The two factors which affect the accumulation rate are the deposition rate and the removal rate. The accumulation rate equals the deposition rate minus the removal rate. The deposition rate is a function of various characteristics of the area, specifically climate, land-use, traffic, and street surface conditions. The removal of pollutants can be accomplished either by street cleaning, traffic-induced turbulence, or naturally by winds or rains. The difference between the accumulation and deposition rates at any time is assumed to be caused by material blown from the street surface by wind or traffic-induced turbulence. This material can remain suspended in the air, but most of it settles to the ground within about 30 feet (10 meters) of the roadway.

Figures 7-3 and 7-4 are plots showing the observed street surface loading values as a function of accumulation time for the Surrey Downs basin. Plots for the other study areas are shown in Appendix B as Figures B-1 through B-5. The data has been separated by test area, season, and if the test basin was undergoing intensive street cleaning or no street cleaning. Figure 7-3 shows that for periods of no street cleaning in the dry season, accumulation periods of up to about 45 days were observed in some cases. However, during periods of intensive street cleaning, the accumulation periods were much shorter and did not exceed five days.

There is appreciable scatter in this data, especially for the low accumulation periods. Much of this scatter is because of the relatively low street surface loadings observed. The accumulation curves shown on these figures were determined using a combination of least squares multiple regression curve fitting techniques and Student's "T" analyses. The curve fitting procedures used require that the variations be evenly distributed throughout the range of conditions and that the observations are evenly spread over the range of the independent variable (accumulation period in this case). Therefore, the accumulation data was log transformed before the curve fitting techniques were used. Even so, the resultant curves had very poor regression coefficients. The accumulation information was also analyzed by stratifying the data into relatively short accumulation periods. These periods corresponded to a tenth of a day or less, a tenth to two days, two to five days, five to ten days, ten to fifteen days, fifteen to twenty-five days, and greater than twenty-five days. The data was also separated for the dry and wet seasons.

Significant differences were identified by Student's "T" analyses conducted on accumulation data for the different seasons. The median values for each of several accumulation period groupings were used to construct the accumulation trend shown on these figures. If two adjacent accumulation periods did not show significant differences, then they were combined and the trend was flat over that range of accumulation. The dry season samples were also separated for data collected during 1980 and for data collected during 1981. In almost all cases, the 1981 dry period had street surface loading values significantly greater than the 1980 dry period during the time of no street cleaning. The wet season data is not separated for analyses by year because most of that data was collected during continuous months during the fall and winter of 1980 and 1981. The 1980 and 1981 dry seasons, however, were separated by the five month wet season. It is not known why the 1981 loadings were significantly greater than the dry period 1980 loadings. During a previous study in Reno and Sparks, Nevada (Pitt and Sutherland, 1982), street surface loading values were obtained from a variety of street surface conditions throughout the Truckee Meadows area during two adjacent six-week periods during the summer of 1981. The observed loading values were significantly different during the two adjacent periods possibly because one of the periods was associated with much greater winds. In most cases, the windy period had much larger street surface loading values and larger deposition and accumulation rates. This was probably due to the nature of the sources of street surface particulates in the Reno and Sparks area (probably

FIGURE 7-3

SURREY DOWNS-WITHOUT STREET CLEANING

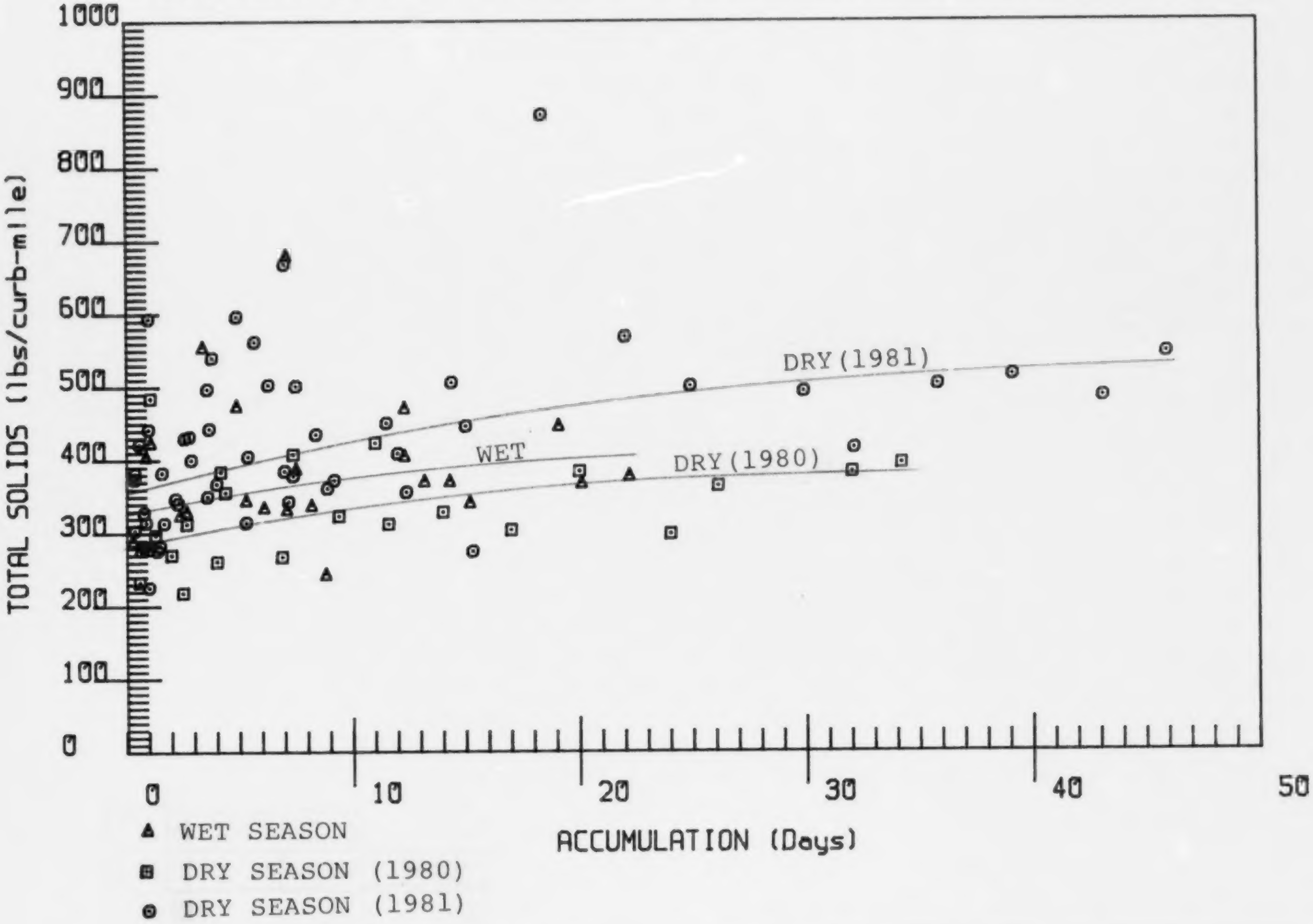

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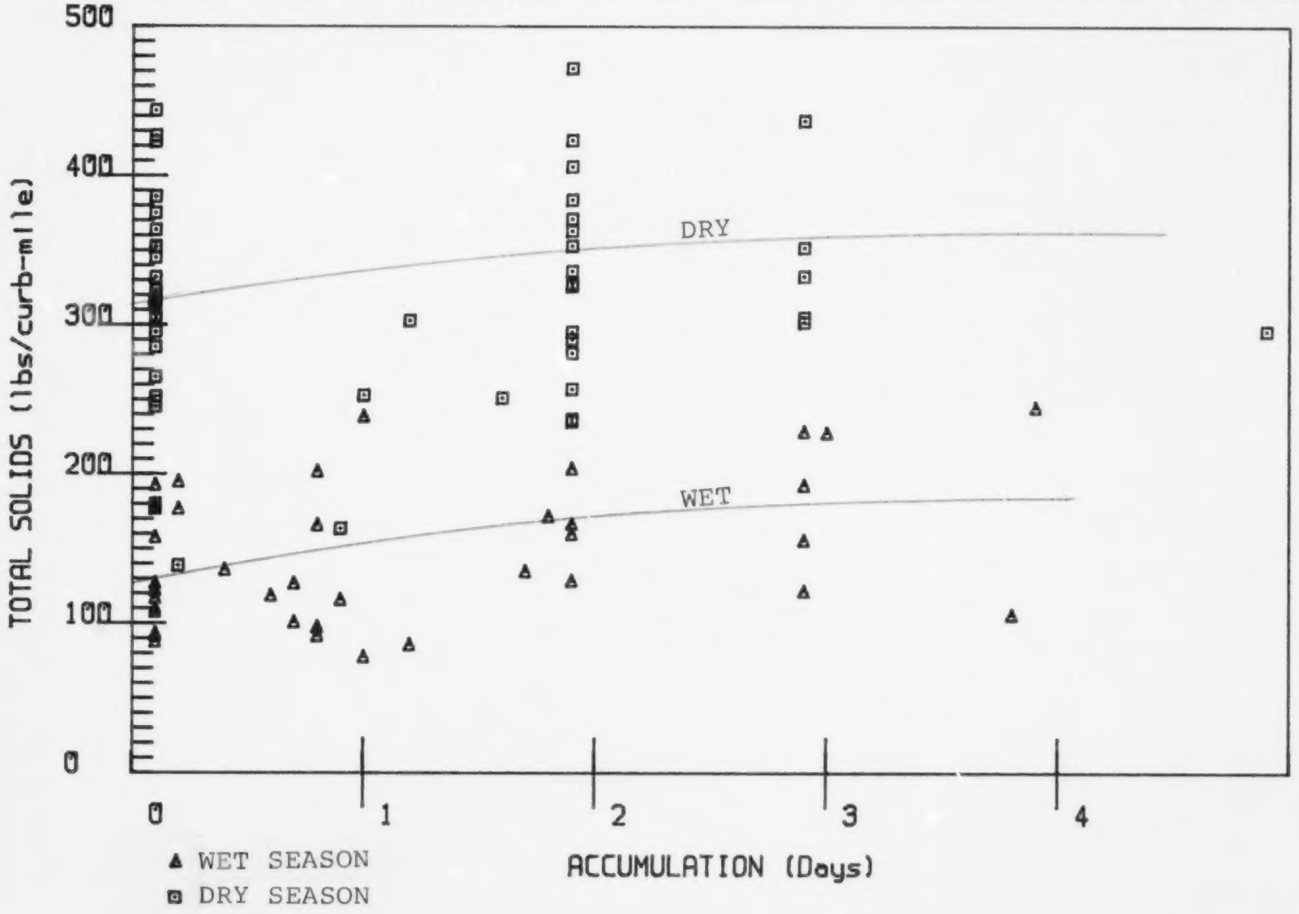
FIGURE 7-4

SURREY DOWNS-WITH STREET CLEANING:ACCUM.



transported sands from the surrounding dry areas or from nearby unlandscaped or construction areas). It is not known if the wind conditions during these two dry periods in Bellevue were significantly different.

Table 7-1 summarizes the estimated accumulation and deposition rates along with the street surface loading values associated with different times of accumulation. Also shown on this table are the calculated standard deviations associated with the observed loadings during each time period. The standard deviations range from about 50 to 200 lbs/curb-mile (14 to 57 g/curb-meter) per day, while the loading values range from about 200 to 1,000 lbs/curb-mile (57 to 280 g/curb-meter) per day. In many cases (especially for very clean street surface conditions) the observed loading variations can be quite large when compared with the loading values. The expected variations in loadings decrease for the larger loading values associated with the longer accumulation periods. The standard deviation values can be used to construct the approximate confidence intervals. The band that is one standard deviation wide on both sides of the mean value would contain about two-thirds of the data points. A band three standard deviations wide would contain about 95 percent of the data points. When all of these calculated curves with their confidence intervals are plotted together, most of the bands overlap, but three separate categories are evident. The lowest loadings were found on 148th Avenue S.E. throughout a long accumulation period, even though the initial loading values were not the lowest. Lake Hills and 108th Street (during the dry 1980 season and during periods without street cleaning) had higher accumulation rates than most of the other areas and always had higher loadings than the other areas. The rest of the categories all seem to fall together, with initial loading values ranging from about 150 to 350 lbs/curb-mile (42 to 100 g/curb-meter) per day and loadings of about 350 to 550 lbs/curb-mile (10000 to 160 g/curb-meter) per day after about a maximum of 40 days accumulation. The 148th Avenue site had observed loadings between about 200 to 250 lbs/curb-mile (57 to 70 g/curb-meter) per day throughout a long accumulation period. The 108th Street and Lake Hills dry 1980 periods had much higher loading values, ranging from initial values of 450 to 500 lbs/curb-mile (130 to 140 g/curb-meter) increasing to high values of between 800 to 1,000 lbs/curb-mile (230 to 280 g/curb-meter). The Lake Hills periods with street cleaning also had very low accumulation rates, comparable to the low rates observed in 148th Avenue. The Surrey Downs (with street cleaning) accumulation rates, however, were quite large and were comparable to the dry 1980, Lake Hills and 108th Street rates.

These Bellevue loading values and accumulation rates are compared with values obtained in other locations on Table 7-2. The initial loading rates for Bellevue, which range from 200 to 500 lbs/curb-mile (57 to 140 g/curb-meter), are within the low range of values reported elsewhere, and generally correspond to other locations having smooth streets in good to fair condition. Rough streets in other locations had loadings more than five times the Bellevue loadings. Similarly, the observed Bellevue deposition rates also appear to be on the low end of the rates observed elsewhere, and also generally correspond to smooth streets in good to fair condition or in residential areas.

Table 7-1. Approx. Total Solids Street Dirt Loadings and Accumulation Rates

			Days of Accumulation						
Surrey Downs			0	2	5	10	15	25	40
- without cleaning	wet season	χ(1)	340	345	360	380	390	410	-
		σ(2)	90	170	190	140	50	50	-
		rate(3)	-	4	4	4	2	2	-
	dry (1980)	χ	285	300	320	340	350	370	390
		σ	60	70	80	90	70	160	60
		rate	-	8	7	4	2	2	1
	dry (1981)	χ	360	375	400	430	450	490	525
		σ	80	90	100	110	90	210	80
		rate	-	8	8	6	4	4	2
- with cleaning	wet season	χ	130	170	200	-	-	-	-
		σ	30	80	110	-	-	-	-
		rate	-	20	10	-	-	-	-
	dry season	χ	315	350	365	-	-	-	-
		σ	70	80	90	-	-	-	-
		rate	-	18	5	-	-	-	-
Westwood Homes Road - without cleaning	wet season	χ	270	290	310	350	380	420	-
		σ	140	150	220	90	230	260	-
		rate	-	10	8	7	6	4	-
	dry (1980)	χ	350	370	410	460	500	550	570
		σ	110	60	270	170	130	80	80
		rate	-	13	10	10	8	5	1
	dry (1981)	χ	160	180	210	250	290	350	390
		σ	60	70	90	120	40	90	130
		rate	-	10	10	8	8	6	3
108th Street - without cleaning	wet season	χ	245	260	290	320	330	360	-
		σ	130	140	140	100	40	130	-
		rate	-	10	8	6	3	2	-
	dry (1980)	χ	460	490	540	620	680	820	920
		σ	200	220	240	320	480	390	430
		rate	-	17	16	15	14	12	7

(1) average loading value (lb/curb-mile)
(2) approx. standard deviation of the loading value
(3) approx. accumulation rate (lb/curb-mile/day)

Table 7-1. Loadings and Accum. Rates (Con't)

			Days of Accumulation						
			0	2	5	10	15	25	40
Surrey Downs 108th Street (Con't) - without cleaning	dry (1981)	χ	300	320	340	360	380	420	440
		σ	120	110	100	100	100	150	210
		rate	-	10	7	4	4	4	1
Lake Hills - without cleaning	wet	χ	170	200	270	290	305	-	-
		σ	60	60	230	80	130	-	-
		rate	-	15	20	4	3	-	-
	dry (1980)	χ	500	540	600	660	710	750	770
		σ	160	190	350	310	330	270	420
		rate	-	20	20	12	10	4	1
	dry (1981)	χ	170	200	270	290	305	310	320
		σ	50	70	160	140	140	110	170
		rate	-	20	15	4	3	1	1
Lake Hills - with cleaning	wet	χ	170	185	195	-	-	-	-
		σ	60	60	170	-	-	-	-
		rate	-	8	3	-	-	-	-
	dry	χ	170	185	195	-	-	-	-
		σ	50	65	120	-	-	-	-
		rate	-	8	3	-	-	-	-
148th Ave. SE - without cleaning	dry	χ	200	205	210	215	220	225	230
		σ	60	60	80	100	70	30	10
		rate	-	3	2	1	1	1	1

Table 7-2. BELLEVUE STREET DIRT DEPOSITION RATES COMPARED WITH DATA FROM OTHER AREAS

Location	Initial Loading Value (lb/curb-mi)	Deposition (Initial Accumulation) Rate (lb/curb-mi/day)
Bellevue, Washington		
Lake Hills and 108th St., Dry period 1980	500	20
148th Ave., S.E. (heavy traffic)	200	3
All other study sites and periods	250	12
Reno/Sparks, Nevada(1)		
Smooth streets and gutters in good condition	270	2.6
Other smooth streets and intermediate streets	710	6.1
Rough streets	2,200	36
New residential areas	2,500	61
Smooth and intermediate streets with smooth gutters (windy)	880	24
Smooth and intermediate streets with lipped gutters (windy)	1,300	53
Rough streets (windy)	1,900	120
San Jose, Calif(2)		
Smooth asphalt, good condition	130	15
Smooth asphalt, fair to poor condition	290	15
Rough asphalt, poor condition	780	20
Oil and screens	1,800	20
Castro Valley, Calif(3)		
Smooth asphalt	300	40
Ottawa, Ontario(4)		
Smooth and moderate textured streets	140	70
Rough streets	700	70
Very rough streets	1,100	70
Nationwide(5)		
Residential (smooth asphalt/good to fair)	400	20
Industrial (rough asphalt/poor)	670	40
Commercial (smooth asphalt/good)	300	15

Sources:
(1) Pitt and Sutherland, 1982
(2) Pitt, 1979
(3) Pitt and Shawley, 1981
(4) Pitt, 1982
(5) Sartor and Boyd, 1972; and Pitt and Amy, 1973

THE DISTRIBUTION OF STREET DIRT IN DRIVING AND PARKING LANES

The amount of material present in the parking lanes is available for removal by street cleaning equipment operating next to the curb. The street surface particulates in the driving lanes, however, cannot be removed by normal street cleaning operations. Tables 7-3 and 7-4 show the results of a series of tests conducted in the Lake Hills and Surrey Downs areas to measure the distribution of street dirt across the street. The test procedures are described in Appendix E and involve taking a second set of subsamples in a test area immediately after a normal full street width sample is obtained. The second set of samples could either be taken from the center of the street to the edge of the parking lane (for driving lane loadings) or from the edge of the parking lane to the curb (for parking lane loadings). These samples were divided into eight different particle sizes for analyses. The full street width loadings for each particle size were compared with the corresponding particle size loadings in the driving lane and parking lane.

The values shown in Table 7-3 for Lake Hills were all obtained during a period of intensive street cleaning, while the values shown in Table 7-4 for Surrey Downs were obtained during a period of no street cleaning. In both cases, about 55 to 65 percent of the total street surface loadings were found in the parking lanes. The actual loading values varied substantially, depending upon the street cleaning operations. For the Lake Hills studies, about 50 to 100 lbs/curb-mile (14 to 28 g/curb-meter) of total solids were found in the parking lane, while 200 to 300 lbs/curb-mile (57 to 85 g/curb-meter) were found in the parking lane in Surrey Downs with no street cleaning. The observed differences in loadings in the driving lanes were much less. The driving lane loadings in Lake Hills ranged from about 50 to 75 lbs/curb-mile (14 to 21 g/curb-meter), while they ranged from about 125 to 150 lbs/curb-mile (35 to 42 g/curb-meter) in Surrey Downs with no street cleaning. This indicates that driving lane loadings are probably increased when the parking lane loadings are also high, due to winds transporting particulates out into the street. High parking lane loadings have been found to be associated with high winds or traffic-induced turbulence blowing the particulates from the center of the street towards the curb (Pitt, 1979). It appears that this process can work both ways and that the percentage distribution of the loadings may remain constant over the relatively narrow range of loadings observed in Bellevue.

The percentage of the larger particulates (between 500 and 6350 microns) in the parking lanes in Lake Hills during street cleaning were quite low due to the street cleaning equipment being much more effective in removing these particulates. Only about 30 to 40 percent of the particles in these particle sizes were found in the parking lanes, while about 60 to 70 percent of the smaller particles were found in the parking lane. The percentage of the largest particle sizes (greater than 6350 microns) in the parking lane in Lake Hills with street cleaning was surprisingly high (about 90 percent) but the actual loadings were very low. The distribution of particulate sizes near the curb was much more even in Surrey Downs during the period of no street cleaning. Generally there were smaller fractions of the finer particulates in the parking lane than for the larger particulates. Again, almost all of the largest sized particles (greater than 6350 microns) were found in the parking

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Table 7-3. LAKE HILLS: DISTRIBUTION OF STREET DIRT IN PARKING AND DRIVING LANES (During a period with street cleaning)

	Particle Size (Microns)								
	<63	63-125	125-250	250-500	500-1000	1000-2000	2000-6350	>6350	Total
3/27/81									
Whole street: % in size	16.7	13.6	18.8	21.9	15.2	6.8	5.5	1.5	100.0%
loading (lb/curb-mi)	27.9	22.7	31.3	36.8	25.4	11.3	9.2	2.4	167
Driving lane: % in size	10.3%	6.4	11.1	20.6	25.5	14.0	12.1	0.0	100.0%
loading (lb/curb-mi)	5.7	3.5	6.1	11.4	14.2	7.8	6.8	0.0	56
% of whole street load	20.4%	15.4	19.5	31.0	55.9	71.7	73.9	0.0	33.2%
Parking lane: % in size	19.9%	17.2	22.7	22.9	10.0	2.9	2.2	2.2	100.0%
loading (lb/curb-mi)	22.2	19.2	25.2	25.4	11.2	3.2	2.4	2.4	111
% of whole street load	79.6%	84.6	80.5	69.0	44.1	28.3	26.1	100.0	66.8%
4/17/81									
Whole street: % in size	15.8%	13.3	19.9	21.6	15.1	6.7	5.4	2.2	100.0%
loading (lb/curb-mi)	28.8	24.3	36.3	39.3	27.6	12.3	9.9	4.1	183
Driving lane: % in size	11.0%	8.6	13.9	21.8	23.7	12.2	7.1	1.7	100.0%
loading (lb/curb-mi)	7.9	6.2	10.0	15.7	17.1	8.7	5.1	1.2	72
% of whole street load	27.4%	25.5	27.5	39.9	62.0	70.7	51.5	29.3	39.3%
Parking lane: % in size	18.9%	16.4	23.7	21.3	9.5	3.3	4.3	2.6	100.0%
loading (lb/curb-mi)	20.9	18.1	26.3	23.6	10.5	3.6	4.8	2.9	111
% of whole street load	72.6%	74.5	72.5	60.1	38.0	29.3	48.5	70.7	60.7%

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Table 7-3. LAKE HILLS: DISTRIBUTION OF STREET DIRT IN PARKING AND DRIVING LANES
(During a period with street cleaning)

Particle Size (Microns)

		<63	63-125	125-250	250-500	500-1000	1000-2000	2000-6350	>6350	Total
5/8/81										
Whole street:	% in size	10.6%	9.5	15.7	24.3	21.4	9.1	6.9	2.5	100.0%
	loading (lb/curb-mi)	12.1	10.8	17.9	27.8	24.4	10.4	7.9	2.9	114
Driving lane:	% in size	8.3%	8.0	13.3	23.0	26.2	13.3	7.7	0.2	100.0%
	loading (lb/curb-mi)	4.8	4.7	7.8	13.5	15.4	7.8	4.5	0.1	59
	% of whole street load	39.7%	43.5	43.6	41.1	63.1	75.0	57.0	3.4	51.4%
Parking lane:	% in size	13.1%	11.0	18.2	25.7	16.2	4.7	6.1	5.0	100.0%
	loading (lb/curb-mi)	7.3	6.1	10.1	14.3	9.0	2.6	3.4	2.8	55
	% of whole street load	60.3%	56.5	56.4	58.9	36.9	25.0	43.0	96.6	44.6%
Average: % of Whole street load in:										
	Driving Lane:	29.2%	28.1	30.2	37.3	60.3	72.5	60.8	10.9	42.6%
	Parking Lane:	70.8%	71.9	69.8	62.7	39.7	27.5	39.2	89.1	57.4%

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Table 7-4. SURREY DOWNS: DISTRIBUTION OF STREET DIRT IN PARKING AND DRIVING LANES

(During a period of no street cleaning)

	Particle Size (Microns)								
	<63	63–125	125–250	250–500	500–1000	1000–2000	2000–6350	>6350	Total
3/5/81									
Whole street: % in size	4.0%	5.2	11.3	19.6	22.9	18.4	15.1	3.5	100.0%
loading (lb/curb-mi)	14.9	19.5	42.1	73.2	85.7	68.9	56.3	12.9	374
Driving lane: % in size	4.0%	4.5	9.6	17.6	25.1	21.9	15.9	1.4	100.0%
loading (lb/curb-mi)	5.8	6.5	13.8	25.3	36.0	31.4	22.9	2.1	144
% of whole street load	38.9%	33.3	32.8	34.6	42.0	45.6	40.7	16.3	38.5%
Parking lane: % in size	4.0%	5.7	12.3	20.9	21.6	16.3	14.5	4.7	100.0%
loading (lb/curb-mi)	9.1	13.0	28.3	47.9	49.7	37.5	33.4	10.8	230
% of whole street load	61.1%	66.7	67.2	65.4	58.0	54.4	59.3	83.7	61.5%
4/13/81									
Whole street: % in size	4.5%	5.0	9.6	16.5	20.9	17.1	17.4	9.0	100.0%
loading (lb/curb-mi)	14.2	15.9	30.3	51.9	65.8	53.6	54.5	28.1	314
Driving lane: % in size	8.1%	5.7	8.8	16.4	25.0	20.0	15.6	0.4	100.0%
loading (lb/curb-mi)	9.8	6.9	10.7	19.8	30.3	24.2	18.9	0.5	121
% of whole street load	69.0%	43.4	35.3	38.2	46.0	45.1	34.7	1.8	38.5%
Parking lane: % in size	2.3%	4.7	10.1	16.6	18.4	15.2	18.4	14.3	100.0%
loading (lb/curb-mi)	4.4	9.0	19.6	32.1	35.5	29.4	35.6	27.6	193
% of whole street load	31.0%	56.6	64.7	61.8	54.0	54.9	65.3	98.2	61.5%

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Table 7-4. SURREY DOWNS: DISTRIBUTION OF STREET DIRT IN PARKING AND DRIVING LANES (cont.)
(During a period of no street cleaning)

	Particle Size (Microns)								
	<63	63-125	125-250	250-500	500-1000	1000-2000	2000-6350	>6350	Total
5/06/81									
Whole street: % in size	8.4%	6.6	10.8	15.3	17.5	14.6	15.6	11.2	100.0%
loading (lb/curb-mi)	36.0	28.5	46.6	65.6	75.0	62.9	66.9	48.3	430
Driving lane: % in size	8.4%	6.0	8.9	15.5	25.3	19.2	15.1	1.6	100.0%
loading (lb/curb-mi)	10.7	7.6	11.2	19.6	31.8	24.3	19.1	2.1	126
% of whole street load	29.7	26.7	24.0	29.9	42.4	38.6	28.5	4.3	29.4%
Parking lane: % in size	8.3%	6.9	11.7	15.2	14.2	12.7	15.8	15.2	100.0%
loading (lb/curb-mi)	25.3	20.9	35.4	46.0	43.2	38.6	47.8	46.2	303
% of whole street load	70.3	73.3	76.0	70.1	57.6	61.4	71.5	95.7	70.5%
Average: % of Whole street load in:									
Driving Lane:	45.9%	34.5	30.7	34.2	43.5	43.1	34.6	7.5	35.5%
Parking Lane:	54.1%	65.5	69.3	65.8	56.5	56.9	65.4	92.5	64.5%

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lane in both test areas.

CHEMICAL STRENGTHS OF STREET SURFACE PARTICULATES

All of the street particulate samples collected during this study were divided into eight separate particle sizes as described in Appendices E and F. Composites of the different samples were made to represent each test area, specific particle size ranges, and time periods. They were then sent to a commercial laboratory (Am Test, Inc., in Seattle) for chemical analyses. The chemical composition information was then used to calculate total sample pollutant values for each sample collected. Tables B-14 through B-18 in Appendix B present the chemical test results. These tables are separated for each test area, and show the observed chemical concentrations of the street dirt for eight particle sizes for up to ten composite periods. Each composite is associated with a specific time period of about two months. The means, standard deviations, and relative standard deviations (standard deviation divided by the mean) of the particle concentrations for each size range and test area are also shown.

The Surrey Downs and Lake Hills street dirt chemical characteristics were separated into wet and dry seasons and were compared using Student's "T" analysis. In most cases, there were no significant differences observed between the wet and dry seasons. However, many of the very largest particle sizes did show significant differences between the wet and dry seasons. In addition, about half of the particle sizes for lead showed significant differences between the wet and dry seasons.

Figures 7-5 through 7-7 show the particle size distributions for dry season particulates, COD, and lead for eight particle sizes and five test areas. Figures B-6 through B-9 in Appendix B show the particle size distributions for wet season particulates, total Kjeldahl nitrogen, total phosphorus and zinc. The solids particle size distributions show that the smallest particle sizes account for a very small fraction of the total material, especially during the wet season when rains are most effective in removing the smallest particles (see Section 9 for a discussion of storm washoff of particulates). During the dry season, the larger particle sizes account for relatively small fractions of the total solids weight. In all cases, 148th Avenue had most of its total solids weight in the particle size range of 250 to 1,000 microns.

The chemical oxygen demand, Kjeldahl nitrogen, and phosphorus concentrations all show high concentrations associated with the smallest particle sizes, small concentrations with the intermediate sizes, and then large concentrations with the larger sizes. This is probably because of the presence of leaves and other organic material associated with the largest particle sizes. The lead and zinc distributions showed typical particle size distributions for heavy metals with the highest concentrations associated with the smallest particle sizes. The lead particle size distributions are also interesting when comparing the different test areas. Westwood Homes Road in the Surrey Downs basin usually had the smallest lead concentrations for all particle sizes, probably because of the small amount of traffic on that

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FIGURE 7-5

DRY SEASON PARTICLE SIZE DISTRIBUTION

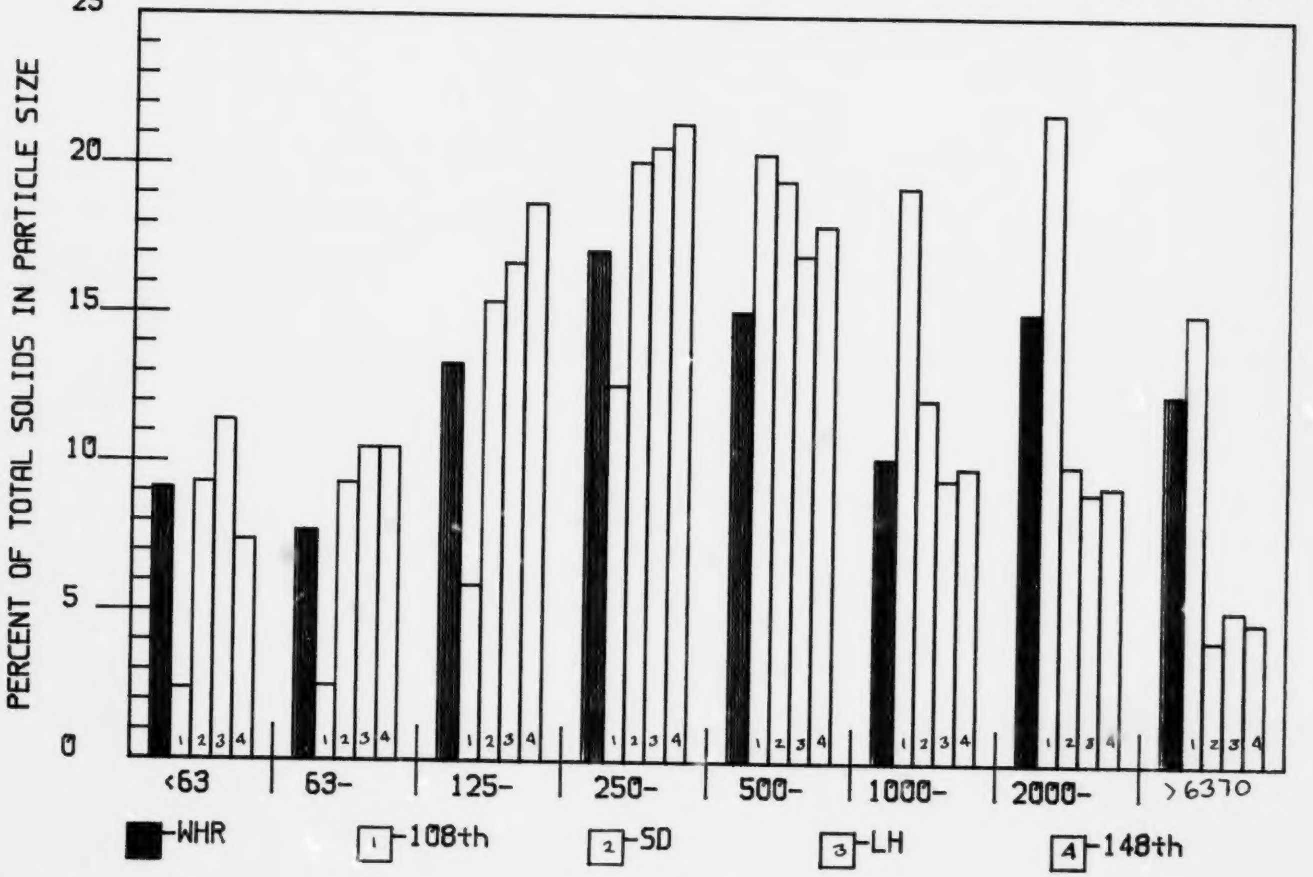

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FIGURE 7-6

COD CONCENTRATIONS BY PARTICLE SIZE (g/kg)

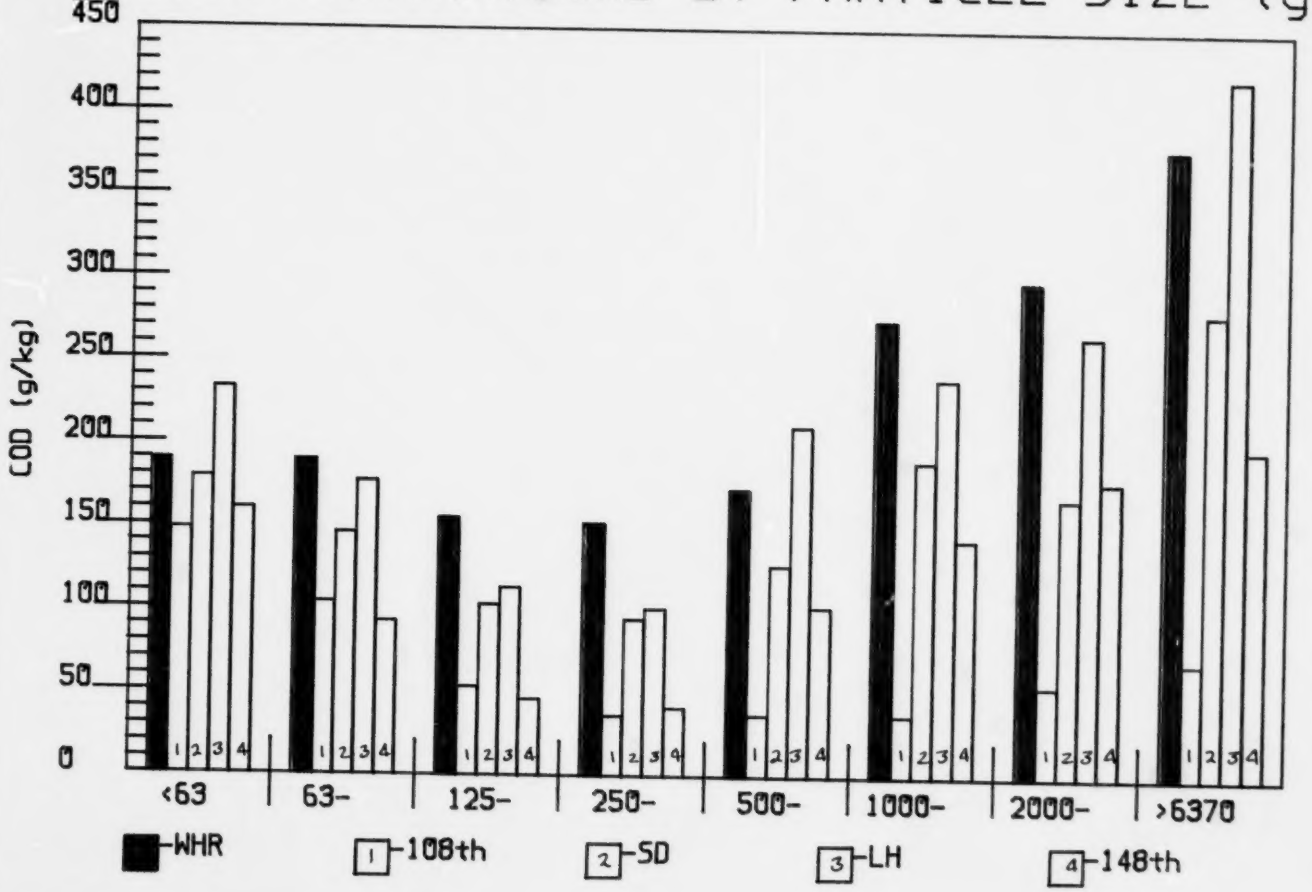

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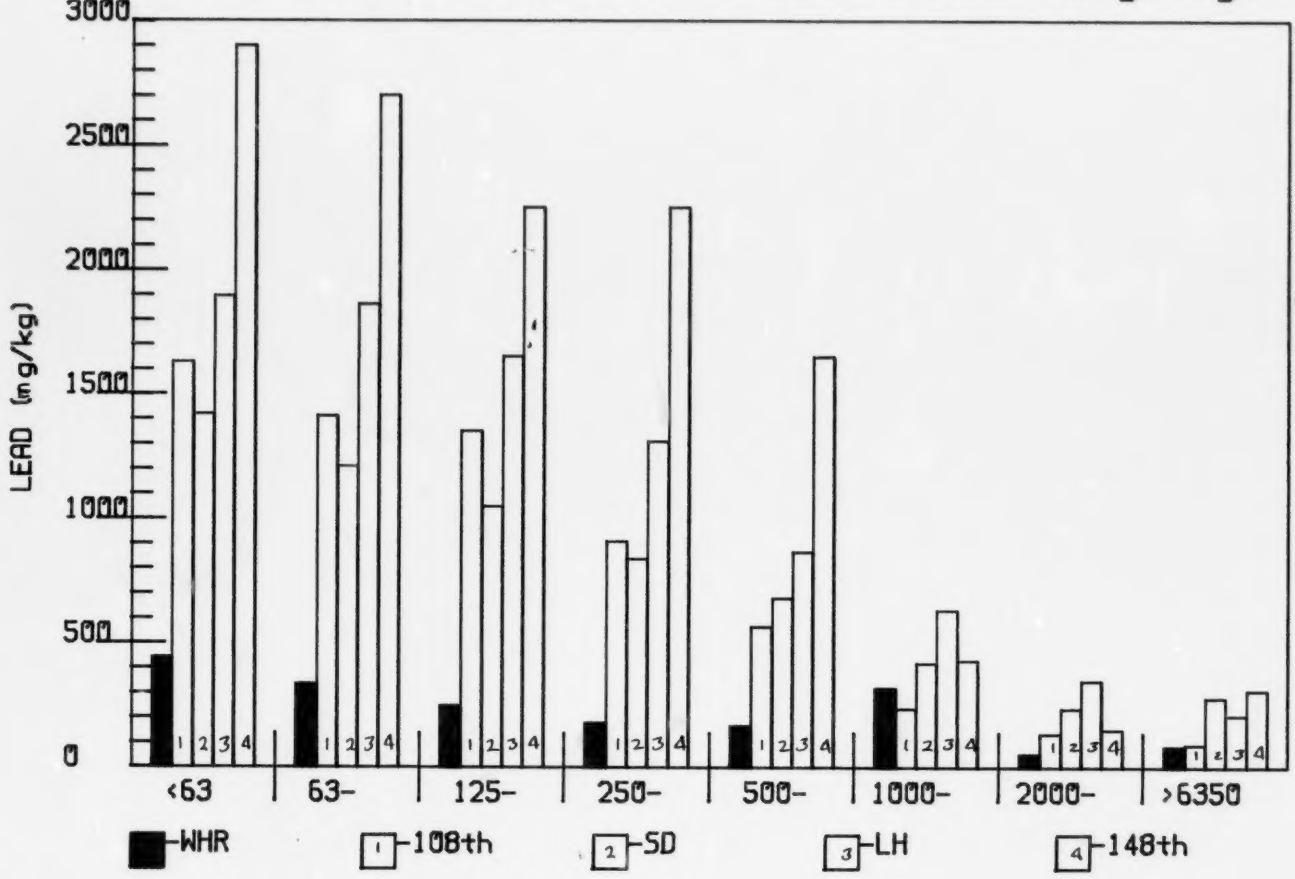
FIGURE 7-7

LEAD CONC. BY PARTICLE SIZE (mg/kg)



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road. However, 148th Avenue is a well travelled street and showed very high lead concentrations, especially in the smallest particle sizes.

Table 7-5 summarizes the size-weighted total particle chemical strengths, along with the median particle sizes. The largest difference in chemical characteristics is shown for lead, especially when comparing Westwood Homes Road with 148th Avenue. The Lake Hills lead concentrations are also greater than the Surrey Downs basin lead concentrations. This may be because of the smaller median particle sizes associated with the Lake Hills samples. Because of the much greater concentrations of lead with the smaller particle sizes, a smaller median particle size would result in a much greater total solid lead concentration. The total solids median particle size for 108th Street street dirt is much greater than the total solids particle sizes for the other test areas, and indicate the presence of many more larger particles on that road than in the other test basins.

Table 7-6 compares these street dirt constituent concentrations with data from other locations. In all cases, the observed Bellevue chemical concentrations are well within the range of values found in the other locations. There is a much smaller difference for these Bellevue street dirt chemical concentrations when compared to other areas than there is for the observed urban runoff concentrations or for the street dirt loadings. Therefore, the street dirt in Bellevue is very similar to the street dirt in other locations studied, but the frequent rains prevent the street dirt from accumulating to large loading values. The total annual rainfall in Bellevue, however, is also similar to many other locations studied. Because of the smaller but more frequent rains in Bellevue, each rain can remove fewer street surface particulates, and the additional runoff volume per rainfall (because of the moist soils) dilutes the pollutants more than for other areas.

Table 7-5. TOTAL STUDY PERIOD STREET DIRT CHARACTERISTICS (mg/kg)

Test Area	Constituent	Size-Weighted Strength	Median Particle Size (microns)
Surrey Downs Main Basin	Total Solids	---	520
	COD	145,000	810
	TKN	1600	420
	Total Phosphorus	575	670
	Lead	745	290
	Zinc	170	350
Surrey Downs 108th St.	Total Solids	---	1370
	COD	51,300	1680
	TKN	455	780
	Total Phosphorus	510	1860
	Lead	460	440
	Zinc	130	1180
Surrey Downs Westwood Homes Road	Total Solids	---	840
	COD	239,000	1960
	TKN	2195	780
	Total Phosphorus	590	890
	Lead	190	420
	Zinc	90	640
Lake Hills	Total Solids	---	420
	COD	192,000	730
	TKN	2310	400
	Total Phosphorus	640	430
	Lead	1170	225
	Zinc	230	260
148th Avenue S.E.	Total Solids	---	610
	COD	104,000	1080
	TKN	850	765
	Total Phosphorus	460	260
	Lead	1540	320
	Zinc	190	360

Table 7-6. BELLEVUE STREET DIRT CONSTITUENT CONCENTRATIONS COMPARED WITH DATA FROM OTHER LOCATIONS (mg/kg)

	Bellevue					Reno/Sparks[1]	San Jose[2]			Castro Valley
Constituent	Surrey Downs	108th St.	Westwood Homes Rd	Lake Hills	148th Ave S.E.		Smooth Asphalt	Poor Asphalt	Oil and Screens	Smooth Asphalt[3]
Cadmium	---	---	---	---	---	<3	2	3	1	---
Chromium	---	---	---	---	---	30	450	450	350	200
Lead	745	460	190	1200	1500	100 to 2,500	5,500	2,000	1,000	1,600
Zinc	170	130	90	230	190	200	750	500	250	200
COD	145,000	51,000	240,000	190,000	100,000	100,000	120,000	110,000	80,000	90,000
Phosphorus	575	510	590	640	460	800	---	---	---	500
Nitrate-N	---	---	---	---	---	25	---	---	---	---
Nitrite-N	---	---	---	---	---	5	---	---	---	---
Kjeldahl-N	1600	460	2200	2300	850	150	2,000	2,300	1,000	1,600

(1) Pitt and Sutherland, 1982
(2) Pitt, 1979
(3) Pitt and Shawley, 1982

Table 7-6. BELLEVUE STREET DIRT STRENGTHS
COMPARED TO OTHER LOCATIONS (Cont.)

Constituent	Ottawa, Ontario(4)			Phoenix(5)	Milwaukee(5)	Bucyrus, Ohio(5)	Baltimore(5)	Atlanta(5)	Tulsa(5)
	Smooth & Moderate Asphalt	Rough Asphalt	Very Rough Asphalt						
Cadmium	--	--	--	4	3	3	8	1	2
Chromium	--	--	--	200	150	200	300	200	100
Lead	1,000	400	250	1,000	800	900	2,000	700	700
Zinc	--	--	--	300	300	250	600	300	200
COD	--	--	--	50,000	20,000	20,000	20,000	30,000	100,000
Phosphorus	--	--	--	--	--	--	--	--	--
Nitrate-N	--	--	--	--	--	--	--	--	--
Nitrite-N	--	--	--	--	--	--	--	--	--
Kjeldahl-N	--	--	--	2,800	500	900	2,000	1,000	2,000

(4) Pitt, 1982
(5) Sartor and Boyd, 1972, and Pitt and Amy, 1973

SECTION 8

SEWER SYSTEM PARTICULATE ACCUMULATION STUDIES

An important element of the Bellevue urban runoff project was the study of storm drainage particulates. The objective of this portion of the program was to describe the quantities and characteristics of storm drainage particulates in the study areas. The storm drainage particulate studies involved both observation and sampling of catchbasin particulates and particulates accumulated in the pipes throughout the Lake Hills and Surrey Downs study areas. Data obtained from these studies were compared to monitored street surface loadings and total runoff yields measured at the outfalls of the two study areas. These mass relationships help define the importance of storm drainage to the total runoff yield. This section of the report provides a summary of the storm drainage particulate data collected during the study.

CATCHBASIN OBSERVATIONS

As part of the experimental design task, random sampling and chemical analyses of about ten catchbasin sediments and water supernatants were collected in both Lake Hills and Surrey Downs. This initial sampling was conducted on December 27 and 28, 1979. The chemical analysis results for the catchbasin samples taken from the Lake Hills study area are presented in Tables 8-1 and 8-2.

Catchbasin sampling and analyses were conducted two times during the first year. The sediment portion of the samples were dried and sieved after their specific gravities were measured, and then composited for chemical analyses. The supernatant portion of the samples were then chemically analyzed. The chemical analysis results for the sediment portion of catchbasin samples collected March 19 and 20, 1980, are presented in Table 8-3. The average wet specific gravity was approximately 1.3 grams per cubic centimeter, or 80 lbs/cubic foot. This average value was lower than expected. The procedures used to obtain these initial catchbasin sediment samples may not have provided representative undisturbed cores. Since the freezing core sampler did not work adequately for the shallow sediment depths encountered, the sediment samples were obtained by hand scooping. The specific gravities and total solids percentages may be low because of the extra water obtained in the scooping procedure. This problem was corrected for the future samples.

Additional samples were collected from January through June of 1981 in selected catchbasins throughout Lake Hills and Surrey Downs. About ten catchbasins were sampled during each of these three sampling efforts. Each

Table 8-1. CATCHBASIN SUPERNATANT QUALITY (Lake Hills, 12/27-28/1979

catch-basin number	total solids (mg/1)	chemical oxygen demand (mg/1)	total Kjeldahl nitrogen (mg/1 as N)	total Phosphorus (mg/1 as P)	Lead (mg/1)	Zinc (mg/1)
592	91.(1) 91.	24.	<.50	.325	.08	1.19
616	88.	27.	.98	.132	.07	.045
626	124.	24.	1.20	.218	.07	.079
524	85.	24.	4.73	.638	.22 .05	.018
528	111.	81.	2.20	.322	.14	.105
535	272.	244.	3.04	6.90 6.75	.11	.218
549	34.	22.	.98 1.40	.082	.09	.033
564	49.	29. 36.	.50	.078	.08	.088
578	158.	90.	5.60 5.60	.690	.45	.126
582	150. 150.	20.	.70	.135	.12	.037

(1) data shown with brackets are replicates

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Table 8-2. CATCHBASIN SEDIMENT QUALITY (LAKE HILLS, 12/27-28/1979)

catch-basin number	total solids %	total Kjeldahl nitrogen (μg/g as N)	Lead (μg/g)	Zinc (μg/g)
592	27.0	794.	580.	166.
616	6.82	342.	236.	159.
626	20.3	747. 1010.	278.	146
524	4.37	1020.	262.	93.0
528	.887	778.	149.	53.5
535	26.4	56.0	13.0	37.0
549	2.49	353.	407.	123.
563	64.8	1470.	507.	211.
578	6.22	2010.	465.	104.
582	52.9	560.	479.	120.

Table 8-3. CATCHBASIN SEDIMENT QUALITY (3/19-20/1980)(1)

Test Basin	catch-basin number	Specific Gravity (gm/cm^2)	Total Solids (%)	Chemical oxygen demand (%)	Total Kjeldahl nitrogen (%-N)	Total phosphorus (µg/g-P)	Lead (µg/g)	Zinc (µg/g)
Surrey Downs	510	1.108	9.29	26.9	.971	2020.	5070.	540.
Surrey Downs	548	1.048	19.2	12.1	.396	411.	806.	137.
Surrey Downs	559	1.660	56.6	9.95 8.59	.791	168.	1325.	245.
Surrey Downs	531	1.041	5.98 5.51	48.9	1.41 1.03	2124	5937. 4370.	1010. 1380.
Surrey Downs	534	1.055	5.88 6.11	44.5	2.75	3720	2890.	1000.
Lake Hills	524	1.738	19.1	4.24	.144	199.	880.	318.
Lake Hills	535	1.932	71.5 69.5	1.57	55.6 µg/g	28.4	16.8 14.2	36.1 39.8
Lake Hills	578	1.026	5.31	26.7	1.12	2170.	2930.	595.
Lake Hills	626	1.088	13.8	3.41	.463	978. 833.	1880.	906.
Lake Hills	616	1.014	26.2	1.45	.213	282.	604.	226.

(1) results on a dry weight basis, except for specific gravity and total solids.

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catchbasin sample was dried, mechanically sieved, and then weighed. Equal fractions of each size category were combined for each sampling period, and were chemically analyzed. Tables 8-4 and 8-5 show the chemical analysis results for these three sampling periods and eight particle sizes for both Lake Hills and Surrey Downs. The catchbasin sediment samples had particle size concentrations very similar to the concentrations found in the street dirt in the respective areas. This indicates that the catchbasin sediment material was mostly made up of street dirt. Tables 8-4 and 8-5 also show calculated total sample chemical concentrations during the early experimental design sampling. These total samples concentrations are reasonable when compared with the particle size breakdowns, but do show very large variations (especially when compared to the small variations in the composited size data). This implies that the particle size distributions changed radically from catchbasin to catchbasin, even though the particles making up the total sediment are quite similar in properties.

Tables D-1 through D-6 in Appendix D show the measured sediment volumes for all structures examined. Most of the catchbasins were about 28 by 22 inches (700 by 560 mm), but some catchments with manholes were as large as four feet (1.2 meters) in diameter. During the first survey, the sediment depths ranged from zero to about 15 inches (0 to 380 mm) in Lake Hills (0 to 6.3 cubic feet, or 0 to 0.2 cubic meter) and zero to 27 inches (0 to 690 mm) in Surrey Downs (0 to 15 cubic feet, or 0 to 0.4 cubic meter). Tables D-7 and D-8 show the relative sediment and supernatant quality observed in the catchbasins during the early sampling periods. The extreme ranges of strengths (mg constituent/kg total solids, or ppm) observed, implies that the particle size varies substantially, by location in the test areas and by time. These values also demonstrate the importance of chemical transfer between the sediments and supernatant, especially since a much smaller storm can flush out all of the supernatant whereas a larger storm would be needed to remove a substantial quantity of sediment. This appears to be more important for COD which is shown to be more soluble than the other constituents observed.

Nine complete catchbasin sediment accumulation inventories were conducted during the project. The first survey was conducted in December, 1979, and the last survey was conducted in January, 1982. The depth of sediment was measured for each catchbasin in which access could be obtained. A summary of the results are presented in Table 8-6. Figures 8-1 through 8-4 are plots of the observed loading conditions for each sampling period.

The sewage systems in Lake Hills and Surrey Downs were cleaned before the beginning of this sampling program. Private streets in Surrey Downs (specifically Westwood Homes Road) did not have their associated drainage systems cleaned. Figures 8-1 through 8-4 (corrected for missing data) show that it required about one year for the sewerage system inlet structures (catchbasins, inlets, and manholes) to reach a steady state loading condition. During the second project year (1981), more frequent (about monthly) observations were made and indicate very little net removal or increase in loadings between the observations. Table 8-7 summarizes the typical stable period loadings and the accumulation rates after cleaning before these stable loading values are obtained. The Lake Hills steady state

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Table 8-4. SURREY DOWNS CATCHBASIN SEDIMENT CHEMICAL QUALITY (mg/kg) BY PARTICLE SIZE

	particle size: microns							
	<63	63-125	125-250	250-500	500-1000	1000-2000	2000-6350	>6350
Chemical Oxygen Demand:								
1/13/81	158,000	145,000	90,400	116,000	177,000	210,000	242,000	176,000
1/26 - 2/4/81	158,000	127,000	89,200	78,800	116,000	205,000	248,000	237,000
2/26 - 6/17/81	156,000	118,000	95,200	103,000	137,000	320,000	327,000	320,000
average	157,000	130,000	91,600	100,000	143,000	245,000	272,000	244,000
standard deviation	1,200	14,000	3,200	19,000	31,000	65,000	47,000	72,000
Total Kjeldahl Nitrogen								
1/13/81	3190	2110	1640	1800	1900	2760	2740	1660
1/26 - 2/4/81	2570	1930	1290	1430	1450	2000	1900	2100
2/26 - 6/17/81	2980	2160	1560	1560	1390	3050	2700	2390
average	2910	2070	1500	1600	1580	2600	2450	2050
standard deviation	320	120	180	190	280	540	470	370
Total Phosphorus								
1/13/81	340	450	626	694	366	970	1090	830
1/26 - 2/4/81	1130	793	635	578	642	1030	1050	844
2/26 - 6/17/81	1180	840	630	570	652	791	1030	620
average	880	690	630	610	550	930	1060	760
standard deviation	470	210	5	70	160	120	30	120
Lead								
1/13/81	1100	910	670	550	540	550	530	250
1/26 - 2/4/81	1200	840	650	570	520	500	370	360
2/26 - 6/17/81	1200	870	530	550	570	570	540	250
average	1170	870	620	560	540	540	480	290
standard deviation	60	35	76	12	25	36	95	64
Zinc								
1/13/81	332	370	166	185	180	214	171	107
1/26 - 2/4/81	456	303	222	217	216	246	198	173
2/26 - 6/17/81	397	300	196	196	208	223	207	170
average	395	320	195	200	200	230	190	150
standard deviation	62	40	28	16	19	17	19	37

Total sample analyses (3/19 - 2 /80) (mg/kg):

	COD	TKN	TP	Pb	Zn
mean	250,000	1225	1690	3400	720
standard deviation	180,000	820	1450	2080	490
number of catchbasins	5	5	5	5	5

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Table 8-5. LAKE HILLS CATCHBASIN SEDIMENT CHEMICAL QUALITY (mg/kg) BY PARTICLE SIZE

	particle size: microns							
	<63	63-125	125-250	250-500	500-1000	1000-2000	2000-6350	>6350
Chemical Oxygen Demand:								
1/13/81	218,000	159,000	157,000	173,000	278,000	300,000	231,000	71,500
1/26 - 2/5/81	225,000	162,000	101,000	114,000	191,000	240,000	193,000	205,000
3/17 - 6/17/81	243,000	197,000	165,000	143,000	251,000	295,000	333,000	301,000
average	229,000	173,000	141,000	143,000	240,000	278,000	252,000	193,000
standard deviation	12,900	21,100	34,900	29,500	44,500	33,300	72,400	115,000
Total Kjéldahl Nitrogen								
1/13/81	3360	2330	1870	2100	3090	3780	2100	379
1/26 - 2/5/81	3820	2540	1950	1930	2620	3260	1900	1200
3/17 - 6/17/81	3610	3160	2170	2170	3360	3220	3020	4840
average	3600	2680	2000	2070	3020	3420	2340	2140
standard deviation	230	432	155	120	370	310	600	2370
Total Phosphorus								
1/13/81	231	398	574	574	742	2160	1550	865
1/26 - 2/5/81	1030	744	589	567	645	957	1280	894
3/17 - 6/17/81	1440	1050	941	693	1095	1580	1750	3652
average	900	730	700	610	830	1570	1530	1800
standard deviation	610	330	210	71	240	600	240	1600
Lead								
1/13/81	2800	2400	2000	1200	950	1000	500	160
1/26 - 2/5/81	1300	1100	830	650	670	480	410	260
3/17 - 6/17/81	1800	1400	1200	920	1100	970	940	890
average	1970	1630	1340	920	910	820	620	440
standard deviation	760	680	600	280	220	290	280	400
Zinc								
1/13/81	621	453	278	210	235	282	171	92
1/26 - 2/5/81	413	321	232	223	236	203	284	599
3/17 - 6/17/81	532	404	359	332	437	372	440	367
average	520	390	290	260	300	286	300	350
standard deviation	100	67	64	67	120	85	135	250

Total sample analyses (early samples only):

	COD	TKN	TP	Pb	Zn
mean (mg/Kg)	74,700	700	750	610	210
standard deviation	108,000	540	790	770	230
number of catchbasins	5	15	5	15	15

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Table 8-6. SUMMARY OF OBSERVED CATCHBASIN, INLET AND MAN-HOLE SEDIMENT VOLUMES, DEC. 1979 THROUGH JAN. 1982 (ft^3)

	Surrey Downs					Lake Hills				
	max	avg	total	fraction of total loading	number of structures	max	avg	total	fraction of total loading	number of structures
Catchbasins	11.2	1.9	80	56%	43	8.3	0.8	55	43%	71
Inlets	19.2	1.7	45	31	27	5.5	0.6	28	22	45
Man-holes	25.9	3.1	19	13	6	15.8	3.0	45	35	15
Total	25.9	1.9	144	100%	76	15.8	1.0	128	100%	131

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FIGURE 8-1

Surrey Downs-Ave. Sediment in Structures

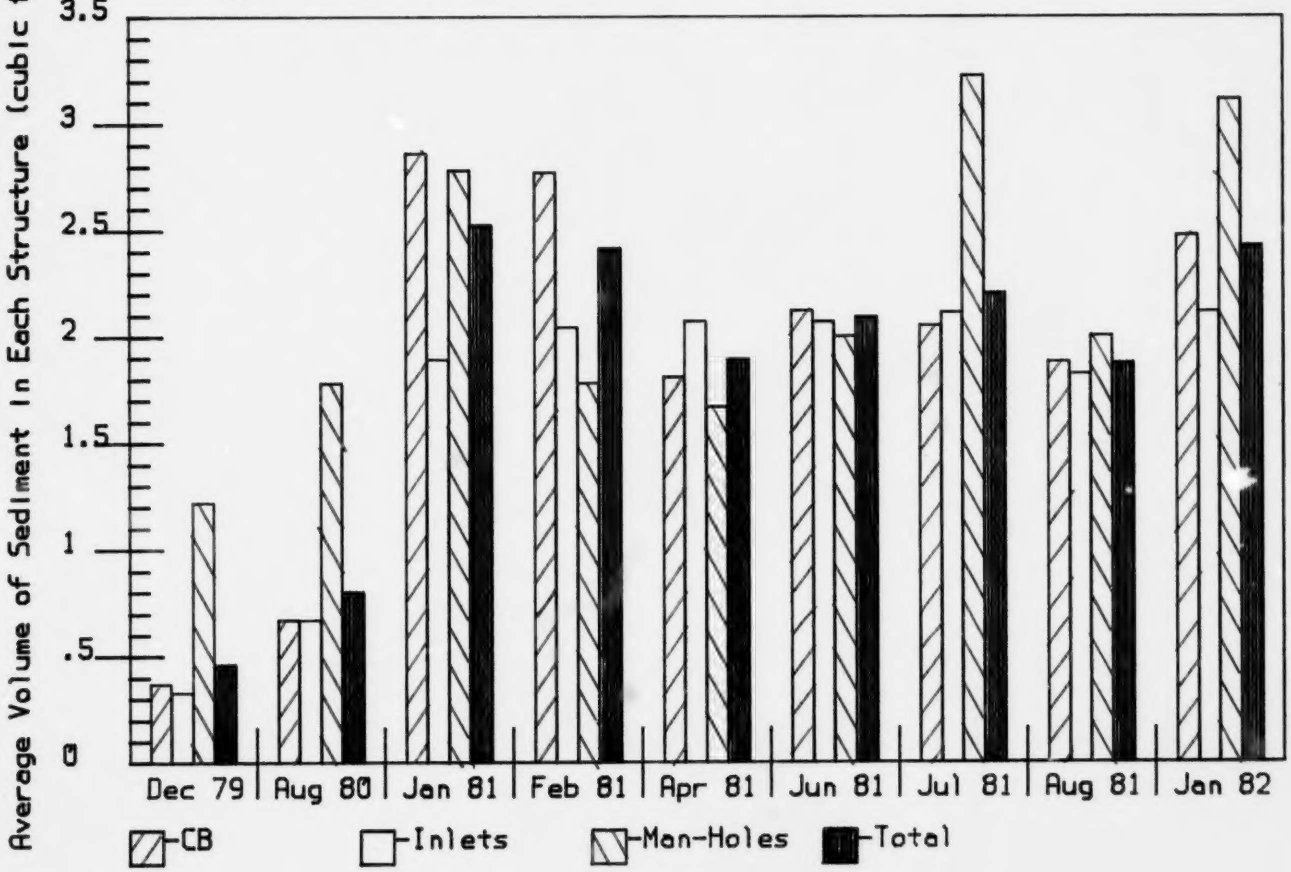

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FIGURE 8-2

Lake Hills-Ave. Sediment in Structures

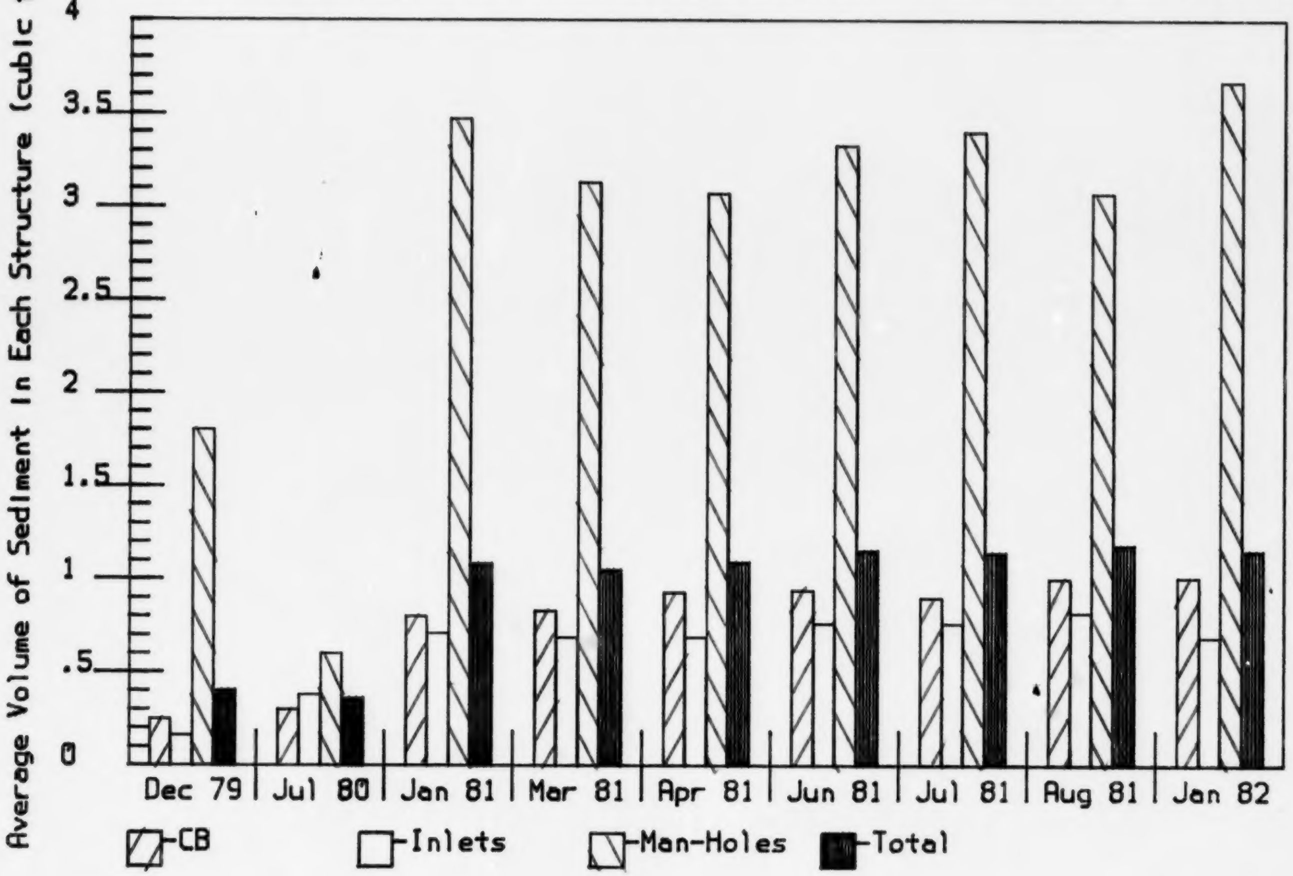

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FIGURE 8-3

Surrey Downs-Total Sediment in Structures

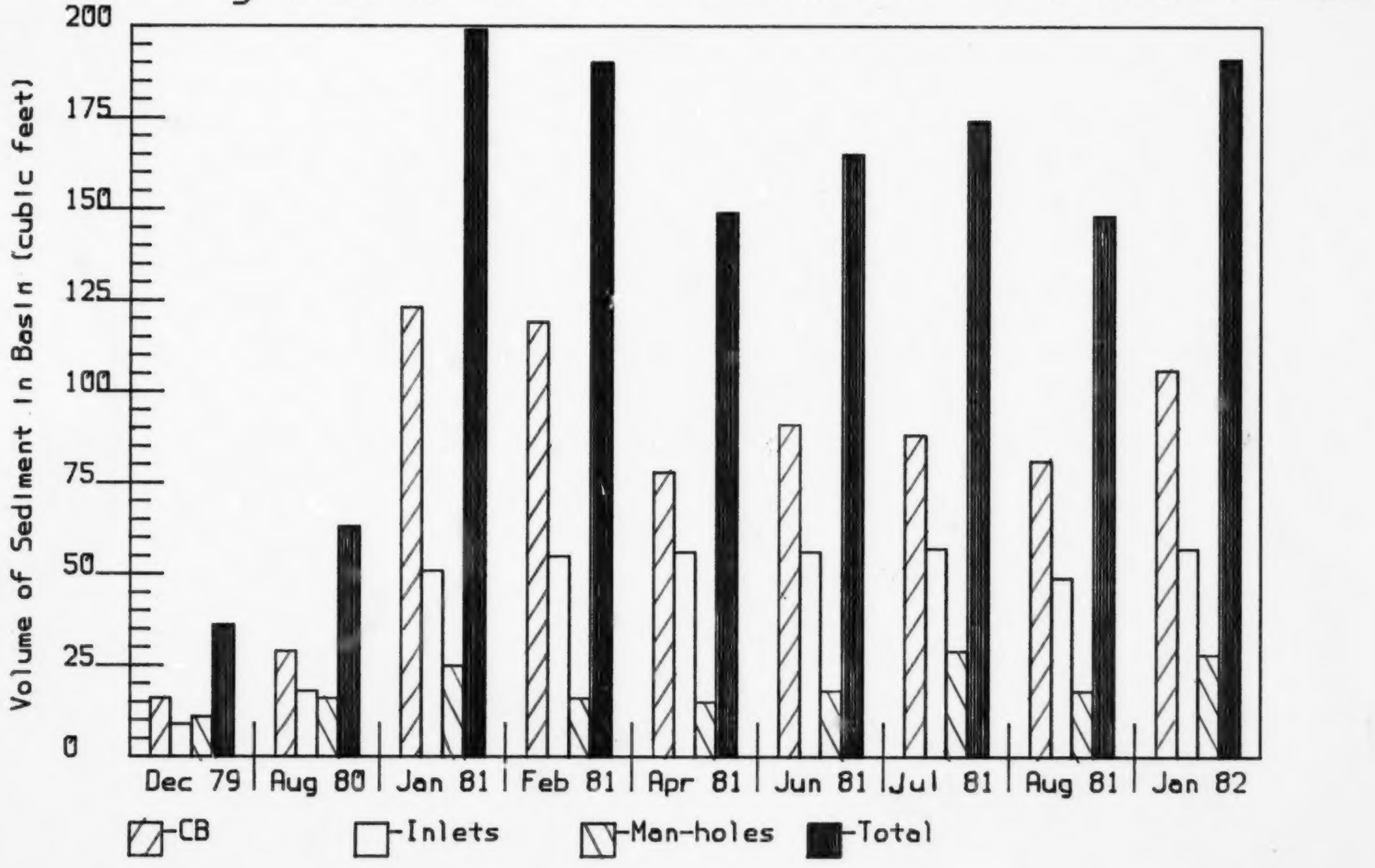

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FIGURE 8-4

Lake Hills-Total Sediment in Structures

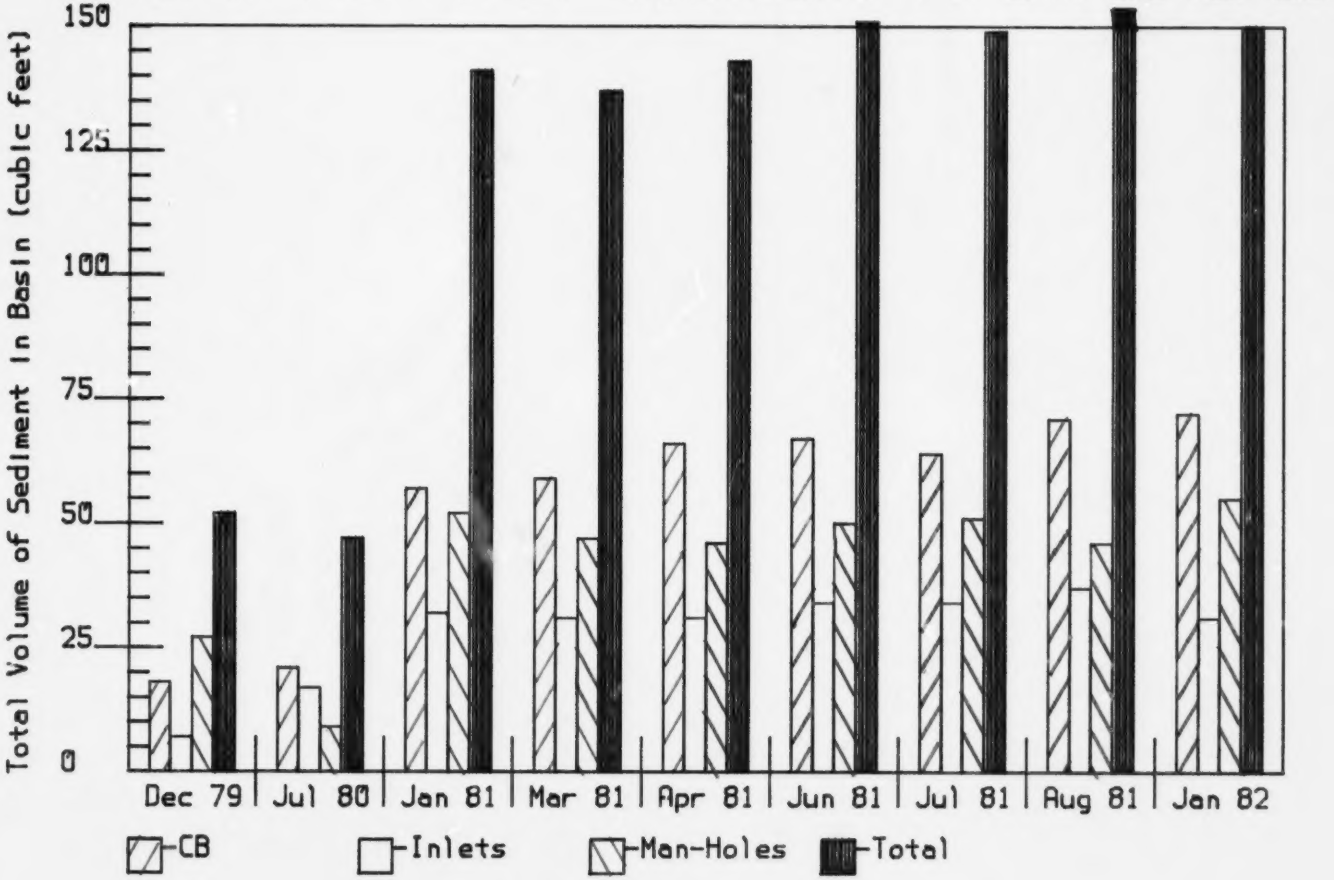

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Table 8-7. TYPICAL SEWERAGE INLET STRUCTURE SEDIMENT VOLUMES AND ACCUMULATION RATES

	stable volume (ft^3)	accum. rate (ft^3/month)	approx. months to stable volume
Surrey Downs:			
Catchbasins	2.2	0.17	13
Inlets	2.0	0.10	20
Man-holes	2.7	0.14	19
Average	2.2	0.15	15
Lake Hills:			
Catchbasins	0.9	0.05	18
Inlets	0.7	0.05	14
Man-holes	3.2	0.14	23
Average	1.1	0.06	18

volumes were about one-half of the Surrey Downs volumes (except for manholes). The approximate time period of particulate accumulation before the stable volume is obtained is also shown on Table 8-7. These periods are between one and two years, with the more common catchbasins requiring about 13 months in Surrey Downs (where the inlet density is about 0.8 inlets/acre, or 2.0 inlets/ha) and 18 months in Lake Hills (with a greater inlet density of about 1.3 inlets/acre, or 3.2 inlets/ha). A conservative estimate, based on the available data, would be about one year. (Observations were not started immediately after the initial cleaning.) Catchbasin, inlet, and manhole cleaning should therefore be performed on about an annual basis to be most cost-effective. Slightly more frequent cleaning may be necessary for smaller inlet structures, less dense spacing of inlets, or during periods of greater than usual rain. Cleaning every six months can probably be considered the maximum effort warranted. A city-wide survey of inlet sizes, inlet densities, and close-by sediment sources (as discussed in the following parts of this section) can be used to effectively determine the optimum cleaning frequency. The additional inlet sediment surveys, carried out by the Bellevue Storm Drainage Utility, will be an effective tool in designing the most appropriate inlet cleaning program.

The total amount of runoff particulates that may accumulate in the inlet structures are shown on Table 8-8. These quantities are about what would be accumulated before the "stable volumes" are obtained. These quantities could be continuously removed, if the inlets are cleaned before the stable volumes are obtained. After the stable volumes are obtained, urban runoff is little affected by the structure. The constant stable volumes experience very little washout and reaccumulations (as shown by the second year loading data). During October, 1981, a very large storm occurred (about four inches). However, no significant difference between the average or total August, 1981, and January, 1982, observations was noted.

An analysis of inlet structure size (volume and depth below outlet) and performance was conducted for the Surrey Downs data. Table 8-9 summarizes these dimensions for catchbasins, inlets, and manholes. The catchbasins and inlets had about one foot (300 mm) available for storage below their outlets, while most of the manhole outlets were on the bottom. Between three and four cubic feet (0.08 and 0.11 cubic meter) of storage were available in the catchbasins and inlets. Table 8-10 shows the observed average volumes and depths of sediment in the inlet structures. Also shown are the portions of the available storage containing the sediment. The stable sediment volumes during the second year were about 60 percent of the available sump volumes for the catchbasins and inlets. Only about one-half inch (13 mm) of sediment was found in the manholes, with outlets on the structure bottoms, while about six inches (150 mm) of sediment were in the inlet and catchbasin sumps. When analyses were conducted for individual structures, wide variations were observed. The depth below the outlet appeared to be the most important factor, but the larger capacity sumps did not always contain the largest amount of sediment. Larger sump volumes would allow less frequent cleaning, while smaller outlet to sump bottom distances were associated with more scour. Manhole #577 (a grease trap with a storage volume of about 48 cubic feet, or 1.4 cubic meters) had the largest sump volume of all inlet structures observed, and usually contained the largest sediment volume. Its

Table 8-8. ANNUAL ACCUMULATION OF SEDIMENTS IN STORM SEWER INLET STRUCTURES

	Annual Total Detention(1)									
	number of structures	avg detention rate (ft3/month)	total solids (ft3)	total solids (lbs)	COD (lbs)	TKN (lbs)	TP (lbs)	Pb (lbs)	ZN (lbs)	percent of total
Surrey Downs:										
Catchbasins	43	0.17	88	8300	2100	10	14	28	6	67%
Inlets	27	0.10	32	3000	750	3.6	5	10	2	25
Man-holes	6	0.14	10	940	240	1.2	1.6	3	1	8
Total/average	76	0.15	130	12,200	3100	15	21	42	9	100%
Annual detention (lb/acre/year):				130	33	0.16	0.22	0.44	0.10	
Lake Hills:										
Catchbasins	71	0.05	43	4000	300	2.8	3.0	2.4	0.8	46%
Inlets	45	0.05	27	2500	190	1.8	1.9	1.5	0.5	28
Man-holes	15	0.14	25	2400	180	1.7	1.8	1.5	0.5	26
Total/average	131	0.06	95	8900	670	6.2	6.7	5.4	1.8	100%
Annual detention (lb/acre/year):				88	6.6	0.06	0.07	0.05	0.02	

(1)Assuming 1.5g/cm^3, or 94 lb/ft^3 and typical pollutant concentrations

Table 8-9. SURREY DOWNS INLET STRUCTURE SIZES

	Catchbasins	Inlets	Man-holes (excluding #577)(1)
Diameter of outlet (inches):			
Average	12	10	all 24
Minimum	8	6	
Maximum	18	36	
Depth below outlet to bottom (feet):			
Average	1.1	0.9	0.02
Minimum	0	0	0
Maximum	2.8	3.4	0.1
Cross-sectional area (square feet):			
Average	3.4	3.9	65.7 (partial)
Minimum	2.5	1.4	52.8
Maximum	6.0	17.4	73.9
Volume below outlet to bottom (cubic feet):			
Average	3.9	3.3	1.3

(1) Man-hole #577 is an oil separator that is 4.1 feet in diameter, with a depth below the 12 inch outlet of 3.7 feet. The total storage volume is 48.3 ft^3. This "man-hole" contained almost all of the debris found in all of the man-holes combined; the other man-holes were empty for most observations.

Table 8-10. SURREY DOWNS INLET STRUCTURE NORMALIZED VOLUMES COMPARED TO AVAILABLE STORAGE

	Dec 1979	Aug 1980	Jan 1981	Feb 1981	April 1981	June 1981	July 1981	Aug 1981	Jan 1982	Stable Period Average
Catchbasins										
Average volume (ft^3)	0.37	0.67	2.86	2.77	1.81	2.12	2.05	1.88	2.47	2.28
Average depth (ft)	0.11	0.20	0.84	0.81	0.53	0.62	0.60	0.55	0.72	0.67
Percent of available storage	9.7%	17.5%	73.7%	71.1%	46.5%	54.4%	52.6%	48.2%	63.2%	58.5%
Inlets										
Average volume (ft3)	0.33	0.67	1.89	2.04	2.07	2.07	2.11	1.82	2.11	2.02
Average depth (ft)	0.09	0.17	0.49	0.53	0.54	0.54	0.55	0.47	0.55	0.52
Percent of available storage	10.0%	20.0%	57.6%	62.4%	63.5%	63.5%	64.7%	55.3%	64.7%	61.7%
Man-Holes										
Average volume (ft3)	1.22	1.78	2.78	1.78	1.67	2.00	3.22	2.00	3.11	2.17
Average depth (ft)	0.02	0.03	0.05	0.03	0.03	0.04	0.06	0.04	0.06	0.04
Percent of available storage			not applicable							---

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stable sediment volume was only about 35 percent of its full capacity, however.

An analysis of the sediment data for the first two sampling periods yielded some interesting observations. Nine of the ten most heavily loaded catchbasins in the first summer inventory for Surrey Downs are located on, or just upstream from, the only two streets in the study area that do not have curbs. Both of the streets (108th Avenue and Westwood Homes Road) have extensive off-street sediment sources located along them and were not cleaned during the study. These nine catchbasins accounted for about 40 cubic feet (1.1 cubic meters) of sediment, or 58 percent of the sediment observed in Surrey Downs catchbasins during that summer inventory. They also accounted for 73 percent of the increase in sediment loadings observed between the first winter and summer inventories.

Table 8-11 shows the heaviest sediment-loaded catchbasins in Surrey Downs during the first two inventories. Eight out of the twelve heaviest loaded catchbasins in the summer inventory were also part of the ten most heavily loaded catchbasins during the winter inventory. Many of these catchbasins were located in the headwaters of the Surrey Downs study area and they may not receive the high runoff rates needed to flush them. However, some flushing was observed farther down in the pipe system (i.e., #566 and #572). A significant portion of the sediment observed in the Surrey Downs catchbasins may not be easily available for runoff transport.

Table 8-12 presents data for the most heavily loaded catchbasins observed in the Lake Hills test area during the first two inventories. Six of the eleven heaviest loaded catchbasins in the summer inventory were also part of the most heavily loaded catchbasins observed in the winter inventory. However, the sediment accumulations in Lake Hills were more evenly distributed among the catchbasins than those in Surrey Downs. The top ten catchbasins in Lake Hills accounted for only about 30 percent of the observed sediment in the summer, whereas the top ten catchbasins in Surrey Downs accounted for about 60 percent of the total summer loading.

PIPE SURVEY AND OBSERVATIONS

A survey of pipe lengths, diameters, slopes, and directions throughout each of the study areas was made during the early months of the project. Frequent observations of sediment accumulations in pipes throughout the two study areas were also made. Very few pipes in either Surrey Downs or Lake Hills had slopes less than 0.01 ft/ft (one percent slope), the slope assumed to be critical for sediment accumulation. In Lake Hills, the average slope of the 118 pipes surveyed was 0.04 ft/ft (4 percent slope). Only nine pipes, or 7.6 percent of those surveyed, had slopes less than 0.01 ft/ft. In Surrey Downs, the average slope of the 75 pipes surveyed was 0.05 ft/ft (five percent). Nine pipes or 12 percent of those surveyed had slopes less than 0.01 ft/ft.

The pipe system data indicates that the two study areas are drained by steeply sloping pipe systems. The chances of finding significant

Table 8-11. SURREY DOWNS CATCHBASIN INVENTORIES - HIGHEST SEDIMENT LOADINGS

Catchbasin Description			SUMMER Sediment loading		WINTER Sediment loading		Change in loading Winter to Summer	
Number	Type CB (1) MH (2)	Location Longest run of upstream pipe (ft)	Rank (out of all catchbasins)	Sediment Volume (ft^3)	Rank (out of all catchbasins)	Sediment Volume (ft^3)	Sediment Volume ± (ft^3)	Percentage change ± (%)
577	CB - oil Sep.	220	1	15.182	1	10.034	+5.148	+51
569	Inlet	0	2	3.640	6	1.040	+3.500	+336
562	CB	370	3	3.563	13	0.712	+2.851	+400
583	Detention pipe	0	4	2.700	2	2.70	0	0
579	Inlet	0	5	2.695	4	1.617	+1.078	+67
580	CB	500	6	2.475	-	0.165	+2.310	+1400
573	CB	1000	7	2.464	-	0.493	+1.971	+400
575	CB	340	8	2.341	-	0.195	+2.146	+1100
534	CB	335	9	2.203	10	0.801	+1.402	+175
578	CB	160	10	2.147	3	2.362	-0.215	-9
548	Inlet	0	11	2.016	8	1.008	+1.008	+100
552	Inlet	0	12	1.870	7	1.020	+1.833	+180
566	CB	2000	-	0.332	5	1.102	-0.770	-70
572	CB	1130	-	0.167	9	0.836	-0.669	-80
559	CB	340	-	1.059	11	0.792	+0.267	+34

(1) Catchbasin
(2) Manhole with catchment

Table 8-12. LAKE HILLS CATCHBASIN INVENTORIES - HIGHEST SEDIMENT LOADINGS

Catchbasin Description			SUMMER Sediment loading		WINTER Sediment loading		Change in loading Winter to Summer	
Number	Type CB (1) MH (2)	Location Longest run of upstream pipe (ft)	Rank (out of all catchbasins)	Sediment Volume (ft^3)	Rank (out of all catchbasins)	Sediment Volume (ft^3)	Sediment Volume $\pm$(ft^3)	Percentage change $\pm$ (%)
594	Inlet	0	1	1.766	-	0.784	+0.982	+125
564	CB	30	2	1.584	-	0.079	+1.505	+1900
530	MH	3400	3	1.418	1	5.674	-4.256	-75
622	Inlet	0	4	1.392	-	0.119	+1.273	+1000
521	CB	55	5	1.350	10	1.157	+0.193	+17
547	CB	1730	6	1.282	-	0	+1.282	-
539	Inlet-MH	0	7	1.256	9	1.257	-0.001	0
523	MH	3630	8	1.256	4	2.513	-1.257	-50
602	Inlet	0	9	1.191	-	0.278	+0.913	+328
587	Inlet	0	10	1.157	7	1.543	-0.386	-25
528	CB	30	11	1.140	6	1.596	-0.456	-29
533	MH	3350	13	1.005	5	1.885	-0.880	-47
535	MH	195	-	0.706	2	5.655	-4.949	-88
581	MH	2360	-	0.707	3	5.650	-4.943	-88
579	MH	2450	-	0.353	8	1.410	-1.057	-75

(1) Catchbasin
(2) Manhole with catchment

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accumulations of sediment in the pipe system are low since scour velocities can be maintained in about 90 percent of the Lake Hills and Surrey Downs storm drainage systems.

During the collection of catchbasin sediment data, routine observations were not made on the amount of sediment in the pipes. However, a special survey was conducted on October 30, 1980. The objective of that survey was to observe the magnitude and characteristics of sediment in the pipes of the two study areas. The following general observations were made:

1. The number of pipes throughout the sewerage systems of both Lake Hills and Surrey Downs that had sediment in their inverts appeared to be minimal.
2. As expected, the pipes that contained significant amounts of sediment were either: mildly sloped (1.5 percent or less); located close to an off-street source of sediment such as steep, sparsely vegetated, unprotected soil slopes; or both mildly sloped and located near a sediment source.
3. The physical characteristics of the sediment in the pipes appeared to correlate well with those of the sediments deposited in the nearest downstream catchbasin or manhole.

Based on the observations made during the October, 1980, field survey, the volume of sediment accumulated in the pipes throughout Lake Hills was approximately 50 cubic feet (1.4 cubic meter). Assuming a specific gravity of 2.0 grams per cubic centimeter, sediment in Lake Hills totaled about 6200 pounds (2800 kg). In Surrey Downs, the pipe sediment volume was estimated at over 700 cubic feet (20 cubic meters) or 87,000 pounds (39,000 kg). Most of this sediment was observed in silted-up pipes along 108th Avenue and Westwood Homes Road. (These streets are not being swept.) The pipe sediment volume estimated to be available for runoff transport in Surrey Downs was about ten cubic feet (0.3 cubic meter) or 1250 pounds (570 kg), and was observed in the pipes connecting catchbasins 506, 507 and 509.

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SECTION 9

STREET CLEANING EFFECTS ON OBSERVED RUNOFF QUALITY

The coordination of street surface sampling, street cleaning operations, and runoff monitoring allowed many different data analyses procedures to be used to investigate possible effects of street cleaning on runoff water quality. The use of two test basins and the rotation of the street cleaning operations also allowed one basin to be compared against the other basin, along with internal basin comparisons. This section is divided into two subsections. The first discusses the washoff of street dirt while the second discusses the observed water quality conditions at the different sites under various street cleaning operations.

WASHOFF OF STREET DIRT

Student's "T" Tests to Compare Before and After Rain Loadings

The first method used to determine the amount of street dirt that was washed off by rain events used data given in Tables B-1 through B-13. The total solids street dirt loadings having less than two days of accumulation were separated into two groups. One group contained loading values that had been affected by a significant rain within two days of sample collection while the other group of data contained total solids loadings that were affected by street cleaning within two days. In addition, these groups were subdivided into dry and wet seasons for each of the five study areas. Paired Student's "T" tests were then conducted to identify significant differences between the loadings before and after street cleaning or rains. Student's "T" tests were also used to compare before and after loadings during wet and dry seasons in each of the five basins.

In about half of the cases, the loadings on the street after the rains were significantly different for the dry versus the wet seasons. Much of this difference may be due to the characteristics of the rains during the two seasons. During the dry season in Lake Hills, the before storm loadings were about 320 to 400 lbs/curb-mile (90 to 110 g/curb-meter) and there was a significant difference between the residual loadings after street cleaning versus after rains. The streets after street cleaning were about 50 lbs/curb-mile (14 g/curb-meter) cleaner than after the rains. During the wet season, the difference was reduced to about 20 lbs/curb-mile (6 g/curb-meter), but the difference was not significant. During the wet season in Lake Hills, the street loadings after street cleaning were about 15 to 20 lbs/curb-mile (4 to 6 g/curb-meter) less than after the rains, but these

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differences were also not significant. The Lake Hills wet season after street cleaning or rain loadings were all about 175 and 225 lbs/curb-mile (50 to 64 g/curb-meter).

Paired "T" test were used to examine the loadings on the streets before the rains and the loadings on the streets after rains in the Surrey Downs and Lake Hills main basins. This data was also separated into three major categories corresponding to runoff volumes of less than 0.1 inch (2.5 mm), between 0.1 and 0.4 inch (2.5 and 10 mm), and greater than 0.4 inch (10 mm). For both the Surrey Downs and Lake Hills data, the small runoff volumes resulted in a street loading difference between 35 and 50 lbs/curb-mile (10 and 14 g/curb-meter) at very significant levels. The removals during runoff events of 0.1 to 0.4 inch (2.5 to 10 mm) were much smaller (between 10 and 20 lbs/curb-mile, or 3 and 6 g/curb-meter) and were not significant. For runoff events greater than 0.4 inch (10 mm), however, the removals were between 75 and 125 lbs/curb-mile (21 and 35 g/curb-meter), also at significant levels. These results were quite surprising as it was thought that the very smallest runoff events would not result in any removal of street surface particulates. It was found in Castro Valley, California (Pitt and Shawley, 1981), that rains having more than 0.4 inch (10 mm) in runoff volume usually corresponded to increases in street surface loadings due to erosion material being left on the streets after these larger rain events. Most of the street dirt removal in Castro Valley was found to occur during rains of between 0.1 and 0.4 inch (2.5 and 10 mm) in runoff. When all of the Bellevue data were considered together, between 35 and 45 lbs/curb-mile (10 and 13 g/curb-meter) were removed by the rains. The typical loadings on the streets before rains in Lake Hills was about 210 lbs/curb-mile (59 g/curb-meter), with about 36 lbs/curb-mile (10 g/curb-meter) removed. In Surrey Downs, the loadings on the streets before rains were larger (330 lbs/curb-mile, or 93 g/curb-meter) and the removals were about 46 lbs/curb-mile (13 g/curb-meter).

The median particle sizes shown on Tables B-1 through B-13 were also compared using paired "T" tests. In all cases the median particle sizes were found to increase by about 100 microns (at significant levels) in Surrey Downs and (at marginally significantly levels) in Lake Hills. When the Surrey Downs data were separated into these three runoff size groupings, the particle size changes associated with the smallest and the largest rains were significant, while the medium rains did not result in any significant changes in median particle sizes. The intermediate runoff volume range had median particle size values that decreased after the rains (but at insignificant values). Large increases in median particle sizes occurred for the largest runoff events (an increase of about 500 microns in Surrey Downs, from initial particle sizes of 570 microns to residual sizes of about 1,100 microns). This very large change could be caused by large removals of small particle sizes and/or increased loadings of the larger particle sizes. This would be expected during the larger rain events which carry substantial erosion material from surrounding areas, some of which may be deposited onto the street's gutters. Table 9-1 summarizes these paired Student's "T" test results for total solids and median particle sizes for both Surrey Downs and Lake Hills.

Table 9-1. STREET DIRT LOADING CHANGES DUE TO DIFFERENT STORM VOLUMES

	Initial	Residual	Change	% Reduction	Significance of change
Surrey Downs					
Total Solids - all	330 lb/curb mi	280	-46	13.9	>99.9%
<0.1" runoff	370	320	-47	12.7	99.5%
0.1 - 0.4" runoff	270	250	-20	7.4	80%
>0.4" runoff	310	190	-120	38.7	98%
Median Size - all	680 microns	770	90	13.2% increase	96%
<0.1" runoff	650	730	83	12.8% increase	96%
0.1 - 0.4" runoff	780	740	-37	4.7% reduction	65%
>0.4" runoff	570	1110	540	94.7% increase	96%
Lake Hills					
Total Solids - all	210 lb/curb mi	170	-36	7.1% reduction	99.5%
<0.1" runoff	190	150	-36	18.9% reduction	97.5%
0.1 - 0.4" runoff	210	200	-12	5.7% reduction	65%
>0.4" runoff	280	200	-78	27.9% reduction	95%
Median Size - all	570 microns	680	110	19.3% increase	85%

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Because of these consistent (but unexpected) results in loadings and particle size changes for different runoff volumes, street dirt washoff was further analyzed to determine effects associated with rain volumes and peak rain intensities. The street surface loadings for total solids and for each of the chemical constituents were plotted on log-log paper. The initial loadings were plotted against the residual loadings and the associated runoff volumes were marked at each point on the graph. The results showed that the residual loadings were apparently unaffected by heavy runoff volumes, but somewhat affected by the initial loadings. About 65 percent of the cases resulted in actual street dirt removals, while the other 35 percent had increases in street loadings due to rain. The average runoff volumes were about 0.1 inch (2.5 mm).

Other plots were made on log-log paper comparing the initial street surface loadings against the runoff volumes. The event mean concentration (emc) values for the runoff events were plotted at each corresponding point. Table 9-2 summarizes the minimum initial street surface loadings for each constituent that corresponded to a fairly small region of maximum runoff concentrations. In almost all cases, the runoff volumes associated with this region of maximum concentrations ranged from about 0.04 to 0.08 inch (1.0 to 2.0 mm). The region for COD was much greater and less defined. There were several exceptions on each plot, but the street loading values shown may indicate a reasonable street cleaning goal to minimize maximum runoff concentrations. The cause and effect relationship on these diagrams, however, was not clear and the presence of the few maximum observed runoff events in this small region may only be coincidental.

Regression Analysis of Street Dirt Washoff

The previous discussion showed that washoff was most likely dependent only on the street loadings before the rain for the rain conditions observed. Figures 9-1 and 9-2 plot the observed initial and residual street surface loadings for each of the three Surrey Downs areas and the Lake Hills and 148th Avenue areas. These plots were ln-transformed in order to obtain a more even spread of the data, so regression analysis could be performed. Again, it is seen that some data points occurred in the region of loading increases, while some also occurred in the region of loading decreases. Table 9-3 summarizes the linear regression equations for each of the study sites and some corresponding washoff values. The regression equations did not have very good regression coefficients. The main Surrey Downs basin had the best regression coefficient of about 0.8. The other regression coefficients were about 0.5. Additional regression relationships were determined for residual load as a function of the peak rain intensity, the residual load as a function of runoff volume, and the initial median particle size versus the residual particle size.

Figures 9-3 and 9-4 show the changes in median particle size for the Surrey Downs, Lake Hills, and 148th Avenue test areas. Again, a large amount of data scatter was observed. In the Surrey Downs basins, 108th Street had the largest initial and residual sizes for most of the data points observed. Westwood Homes Road had some very high median particle sizes restricted to

Table 9-2. STREET SURFACE LOADINGS CORRESPONDING TO A REGION OF MAXIMUM RUNOFF CONCENTRATIONS (LAKE HILLS)

Constituent	street load (lb/curb-mi)	runoff depth (in)	max. runoff conc. (mg/l)
Total Solids	150	0.045 - 0.075	> 200
Lead	0.16	0.045 - 0.08	> 0.3
Zinc	0.035	0.04 - 0.075	> 0.15
Phosphorus	0.08	0.045 - 0.075	> 0.5
TKN	0.25	0.045 - 0.07	> 1
COD	15	0.02 - 0.3	> 50

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FIGURE 9-1

SURREY DOWNS WASHOFF OF STREET DIRT

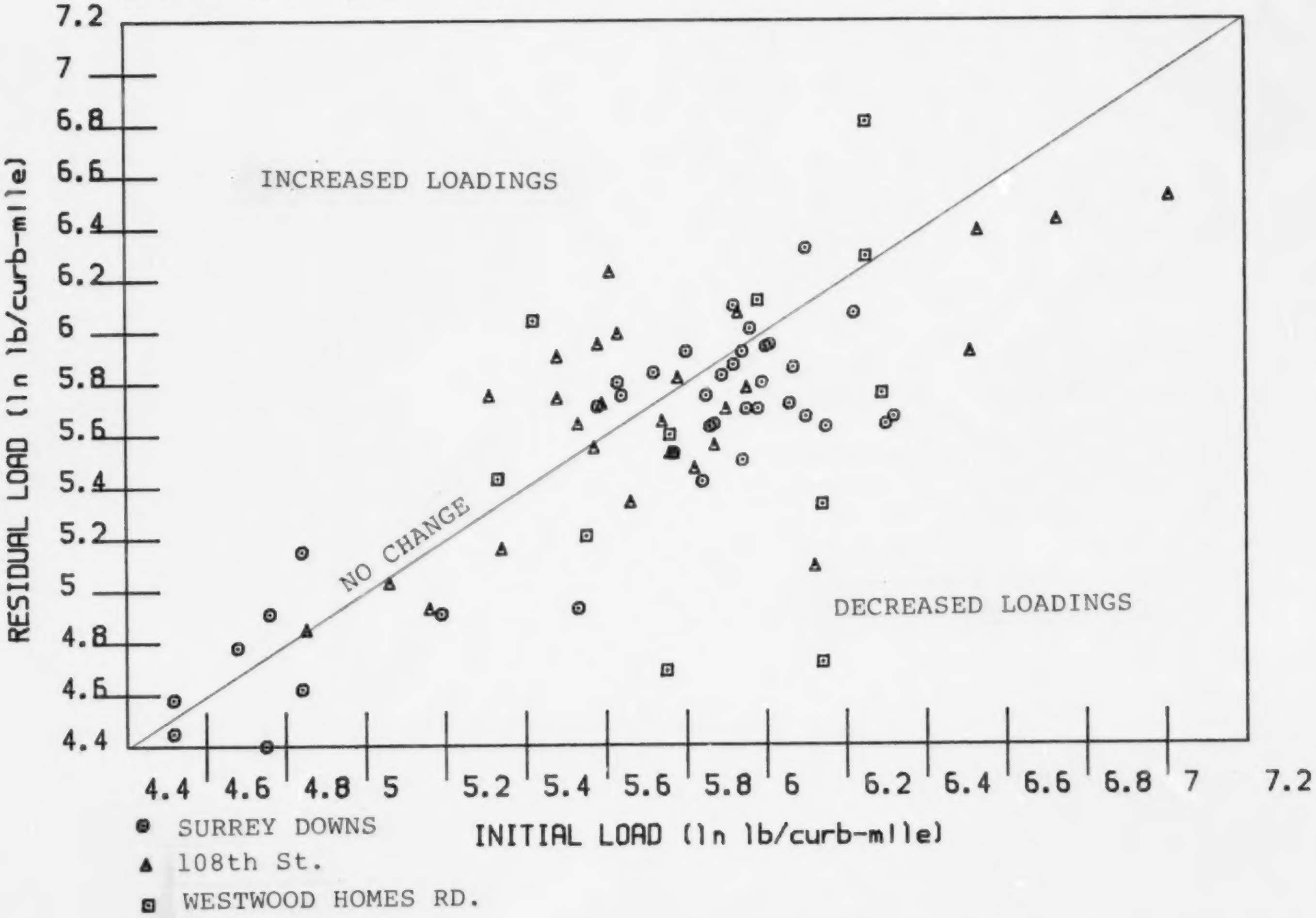

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FIGURE 9-2

LAKE HILLS & 148th AVE STREET DIRT WASHOFF

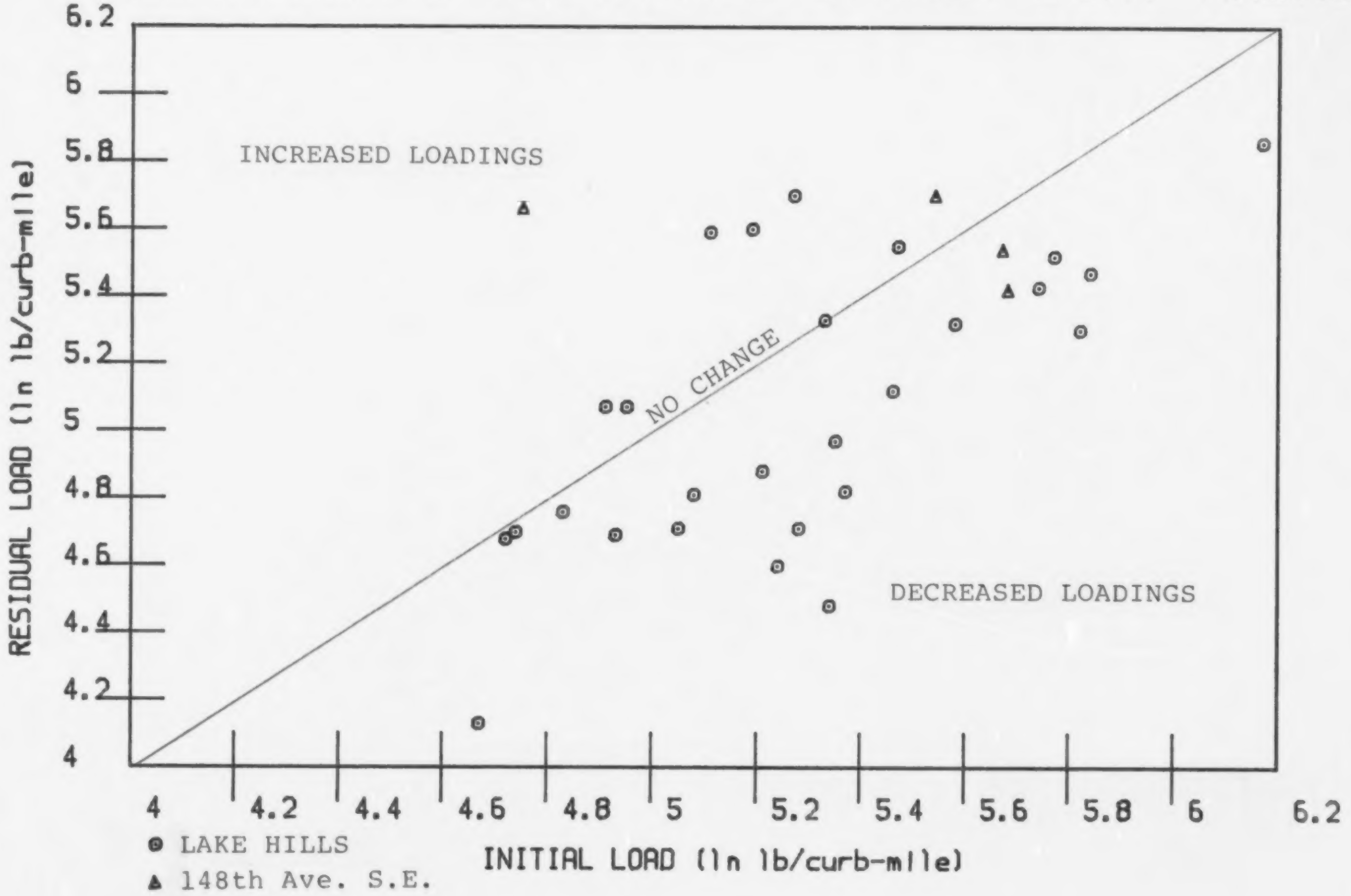

Table 9-3. MODELED WASHOFF OF STREET SURFACE PARTICULATES BY RAINS

	Surrey Downs main basin (1)		Surrey Downs 108th St. (2)		Lake Hills (3)		All Areas Combined (4)	
initial load*	resid. load**	wash-off***	resid. load	wash-off	resid. load	wash-off	resid. load	wash-off
100	103	-3	141	-41	95	5	108	-8
200	185	15	220	-20	162	38	186	14
400	332	68	344	56	278	122	322	78
600	463	137	444	156	377	223	440	160
800	595	205	537	263	475	325	557	243
1000	702	298	610	390	554	446	651	349
1200	830	370	693	507	646	554	761	439

(1) $\ln(\text{resid. load}) = 0.83[\ln(\text{initial load})] + 0.80 \quad r^2 = 0.77 \quad N = 38$
(2) $\ln(\text{resid. load}) = 0.64[\ln(\text{initial load})] + 2.02 \quad r^2 = 0.50 \quad N = 28$
(3) $\ln(\text{resid. load}) = 0.76[\ln(\text{initial load})] + 1.02 \quad r^2 = 0.45 \quad N = 27$
(4) $\ln(\text{resid. load}) = 0.78[\ln(\text{initial load})] + 1.08 \quad r^2 = 0.55 \quad N = 108$
Includes all 3 Surrey Downs sites, Lake Hills and 148th Avenue combined.

* initial loads before rain
** residual loads after rain
*** washoff = initial load - residual load

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FIGURE 9-3

SURREY DOWNS INITIAL SIZE VS RESIDUAL SIZE

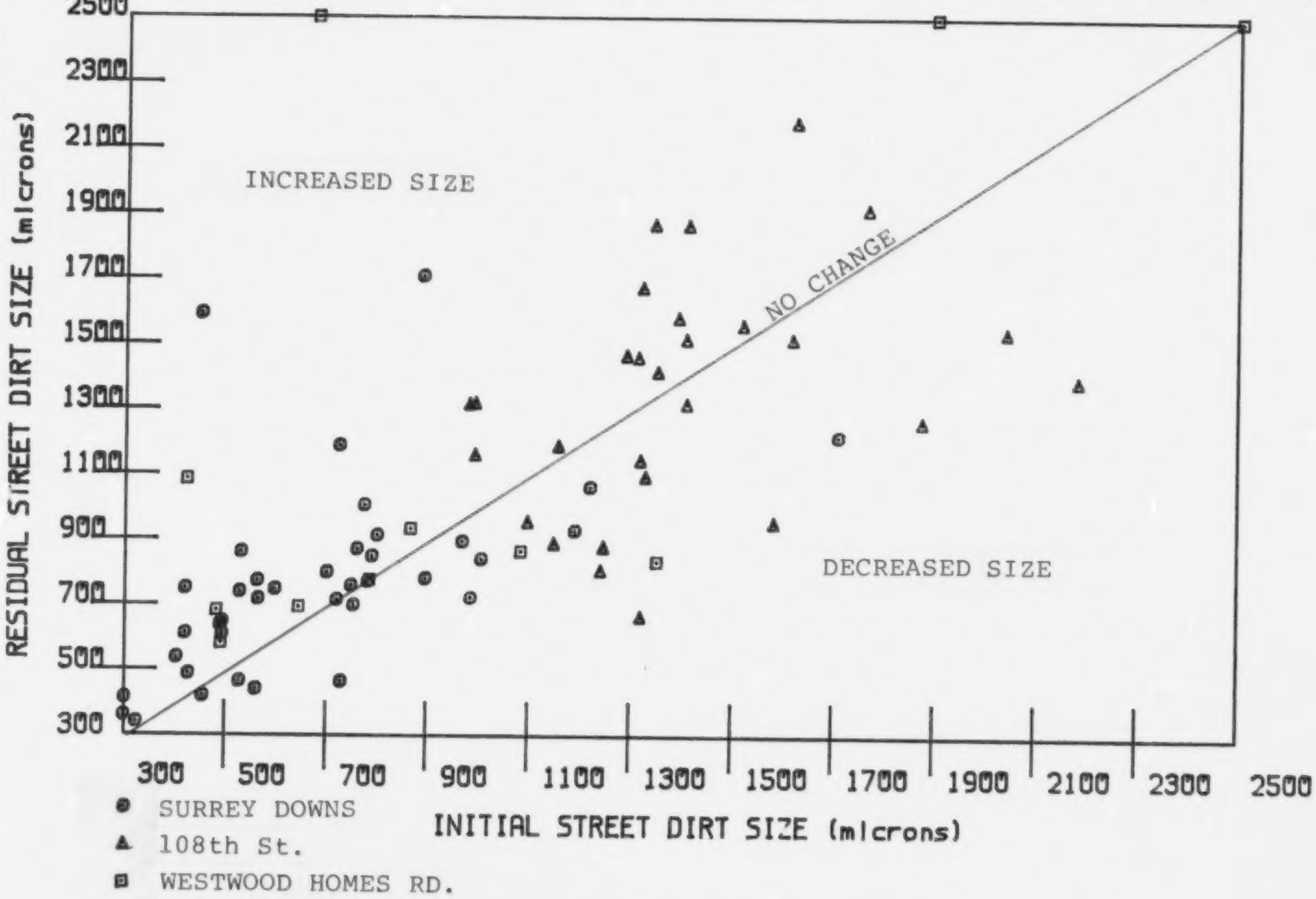
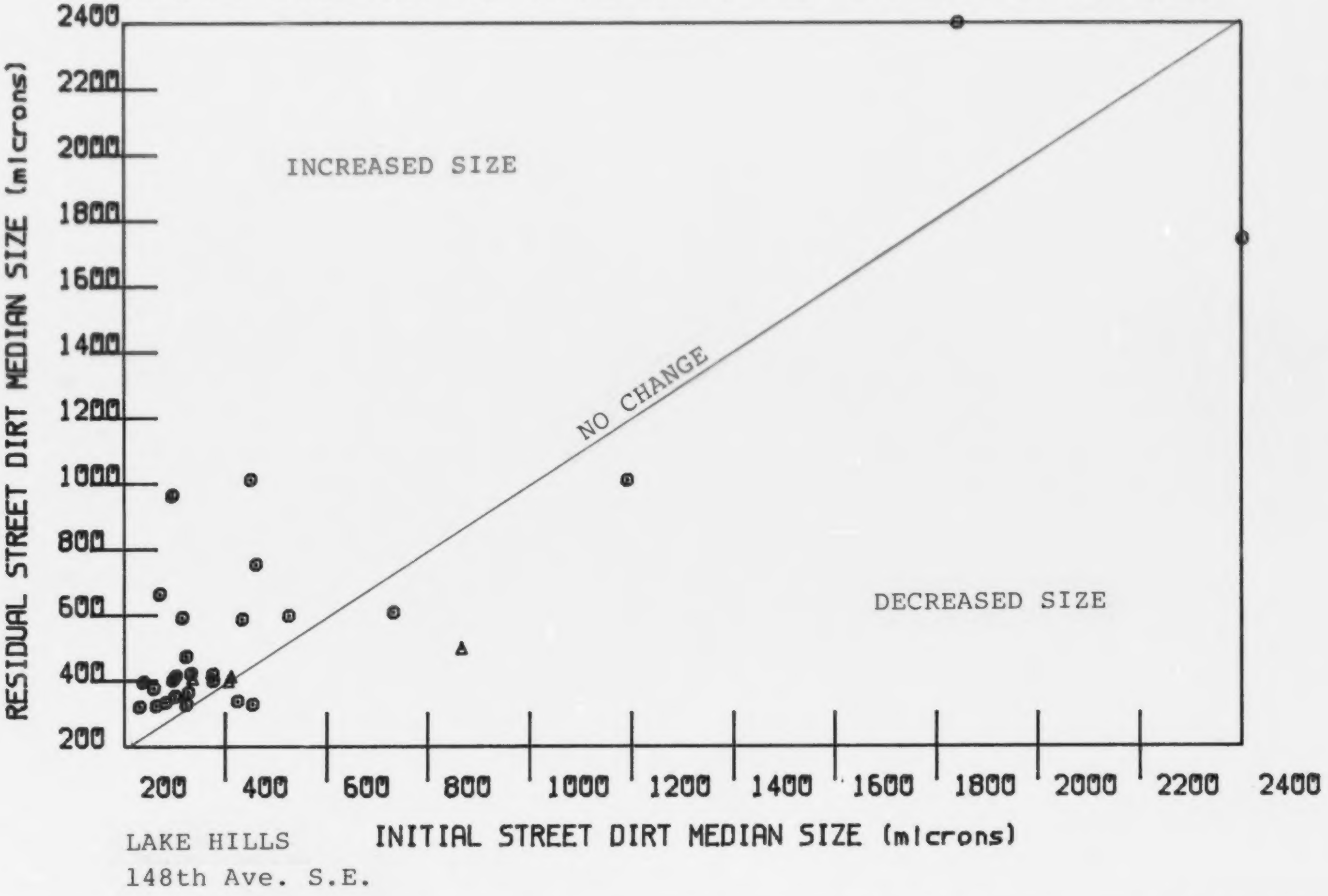


FIGURE 9-4

LAKE HILLS & 148th AVE SIZE CHANGES



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the range of about 300 to 1,000 microns. The 148th Avenue test area and the Lake Hills area had median particle sizes that were quite similar and ranged from about 200 to 600 microns in most cases.

Plots of washoff as a function of runoff volume are shown as Tables B-10 and B-11 in Appendix B. These plots show a fairly random distribution of washoff when compared against runoff volume. These plots indicate that runoff volume had very little effect on the washoff for the range of conditions studied. In most cases, the washoff was about 40 lbs/curb-mile (11 g/curb-meter) for each storm event, irrespective of the runoff volume. There was, however, quite a substantial amount of scatter, especially in the Surrey Downs basins. Figures B-12 and B-13 are similar and compare the loadings on the streets after the rains with the runoff volumes. Again, there is a large amount of scatter in the data with no apparent trend observed. Figures B-14 and B-15 plot all of the data points showing the residual street surface total solids loadings against the peak 30-minute rain intensities. These last two plots also display a large amount of variation with no apparent trend.

Multiple Linear Analysis of Street Dirt Washoff Data

Even though no apparent trends were observed in the preceding simple regression relationships, a more detailed study using stepwise multiple linear regression was used to determine if these parameters may affect residual loadings when considered together. The residual loading values were compared to a combination of initial loads, runoff volumes, peak 30-minute intensities, rain totals, and average rain intensities. Various exponential and straight-line relationships between these parameters were tested with no apparent satisfactory conclusion. These analyses were also conducted for individual particle sizes in order to isolate the major parameters. After many tries and many transformations of the different parameters, the best regression coefficient obtained was a very poor 0.3.

Earlier studies (Sartor and Boyd, 1972) found an exponential washoff relationship relating the residual load to the initial load times a natural exponent of a rain parameter. This model form was also attempted with the Bellevue data, but with disappointing results. The Sartor and Boyd relationship is as follows:

$$N = N_o e^{-krt}$$

Where N = Residual load
N_o = Initial load
r = Rain intensity (in inches per hour)
t = Duration of rain (in minutes)
k = proportionality constant depending on particle size and street surface roughness.

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The factor of rt, or rate times time, is equal to the total amount of

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rainfall. This can be expressed in inches if the k value is multiplied by 60. This equation then simplifies to the following form:

$$N=N_o e^{-kR}$$

The k constant is equal to about 0.6 inch (15 mm) for the particle sizes of concern, and R is the total rain expressed in inches.

This equation was determined from many controlled tests in Bakersfield, California. An artificial rainfall apparatus was used on typical street surfaces. This portable rain simulator applied water uniformly over a section of the street at various controlled "rainfall" rates. The water was supplied from nearby fire hydrants and was sprayed vertically, about four to six feet (1.2 to 1.8 meters) high through hundreds of small jets. The water broke into discrete droplets about the size of common raindrops before they fell to the street surface. The device produced a water flow pattern on the street surface which had the appearance of a moderate to heavy rainfall. Sartor and Boyd found that the soluble street dirt contaminant fractions go into solution with the impacting raindrops and the horizontal sheetflow provided good mixing turbulence and a constant supply of clean water to remove the materials to the gutters. The particulate matter was moved by the impact of falling drops which were then bounced along the street surface by repeating impacts of other drops and carried by sheetflow. They noted that a substantial amount of the particulates were found in small pits, cracks, and other irregularities in the street surface and were not easily removed.

These field tests were conducted on street surfaces having moderate to heavy loadings of total solids in all particle sizes. One concrete and two asphalt streets were flushed by the simulated rainfall for a period of 2.25 hours. Samples of the runoff and the particulates in the gutters were taken every 15 minutes. At the end of the test, the streets were flushed thoroughly with firehoses to wash off any remaining particulates and soluble material. Only two rainfall rates, corresponding to 0.2 and 0.8 inch (5.1 and 20.3 mm) per hour, were used in these tests. Unfortunately, even the smallest rainfall rate was many times greater than any sustained rainfall rate observed in Bellevue. The maximum rainfall rate was much greater than what could ever be expected in Bellevue under most conditions. These very high intensities may only occur for very short periods of time.

Sartor and Boyd found that the initial flows from the streets were quite dirty, but they then became cleaner and cleaner during the period of the test. The pattern of contaminant concentrations in the runoff water followed very similar patterns for each of the test areas and the two rain intensities. The washoff patterns were also similar for all particle sizes. Again, they found that the transport of the particles across the street surfaces fitted the exponential function given previously. The curve fits for these tests were quite good, and total accumulative washoffs for most particle sizes reaching constant values after about 30 minutes of rain. They found that the proportionality constant (k) in the runoff equation was dependent upon the street surface properties, but was not dependent upon the two rainfall intensities that were monitored. They also found that this constant did not vary greatly for different particle sizes.

These very interesting field tests contributed much to the knowledge of street surface particulate washoff, but they were conducted in very controlled situations using rainfall intensities that were not typical of at least Bellevue conditions, and are probably much greater than are likely found in most parts of the country. These tests also did not consider the effects of traffic on the street surfaces during rains. Traffic would have a tendency to remove more of the street dirt particulates during rainfall events (Pitt, 1979). The tests were also conducted on very hot streets during very hot summer days. This is far different than is likely to occur in Bellevue during rain events where the street surfaces and air temperatures are much cooler. The drier and hotter conditions are thought to help retain the soluble materials on the street surfaces and could result in substantial flash evaporation of the rain upon contact with the street surfaces.

Observed Washoff as a Function of Particle Size

Figures B-16 through B-23 are plots of the initial street surface loadings versus the residual surface loadings for each of the eight different particle sizes. Also shown on these figures is the percent washoff, or increase, for each of the rains studied. The smallest particle sizes have most of the data points falling in the washoff category, but some rain events did produce increases in loadings. For particle sizes greater than 2,000 microns, more storm events produced street surface loadings increases than decreases. The before and after street surface loadings for the Lake Hills site were compared using Student's "T" tests to identify significant differences in loadings. There were no differences observed for wet versus dry season washoff quantities, but the initial loadings were significantly greater than the residual loadings for particle sizes smaller than about 500 microns. The smallest particle sizes have the greatest significant washoffs, while particle sizes greater than about 500 microns had lower significant washoff values. When the washoff conditions are averaged, removals show a distinct pattern. Figure 9-5 shows the average percent washoff for each of these particle size ranges. In the smallest particle sizes, the washoff varied from about 40 to 50 percent, while increases were found in the larger particle sizes. The overall washoff averaged about 16 percent. Figure 9-6 shows the size distribution of the washoff material. This size distribution is very similar to the pattern shown in Figure 9-5. Most of the material that washes off the street surfaces occurs in particle sizes less than about 125 microns. Only about ten percent of the washoff material is greater than about 500 microns in size. Again, the largest particle sizes are notably absent from washoff material. Figure 9-7 shows the quantity of material that is washed off of Lake Hills streets by particle sizes. A total of about 30 to 35 lbs/curb-mile (8 to 10 g/curb-meter) is removed from the street surfaces, with about 15 to 20 pounds (7 to 9 kg) of this material in particle sizes smaller than 125 microns.

Table 9-4 shows the estimated washoff percentages for the street surface pollutants. For all sites, about 14 percent of the total solids would be

FIGURE 9-5

PERCENT WASHOFF BY PARTICLE SIZE

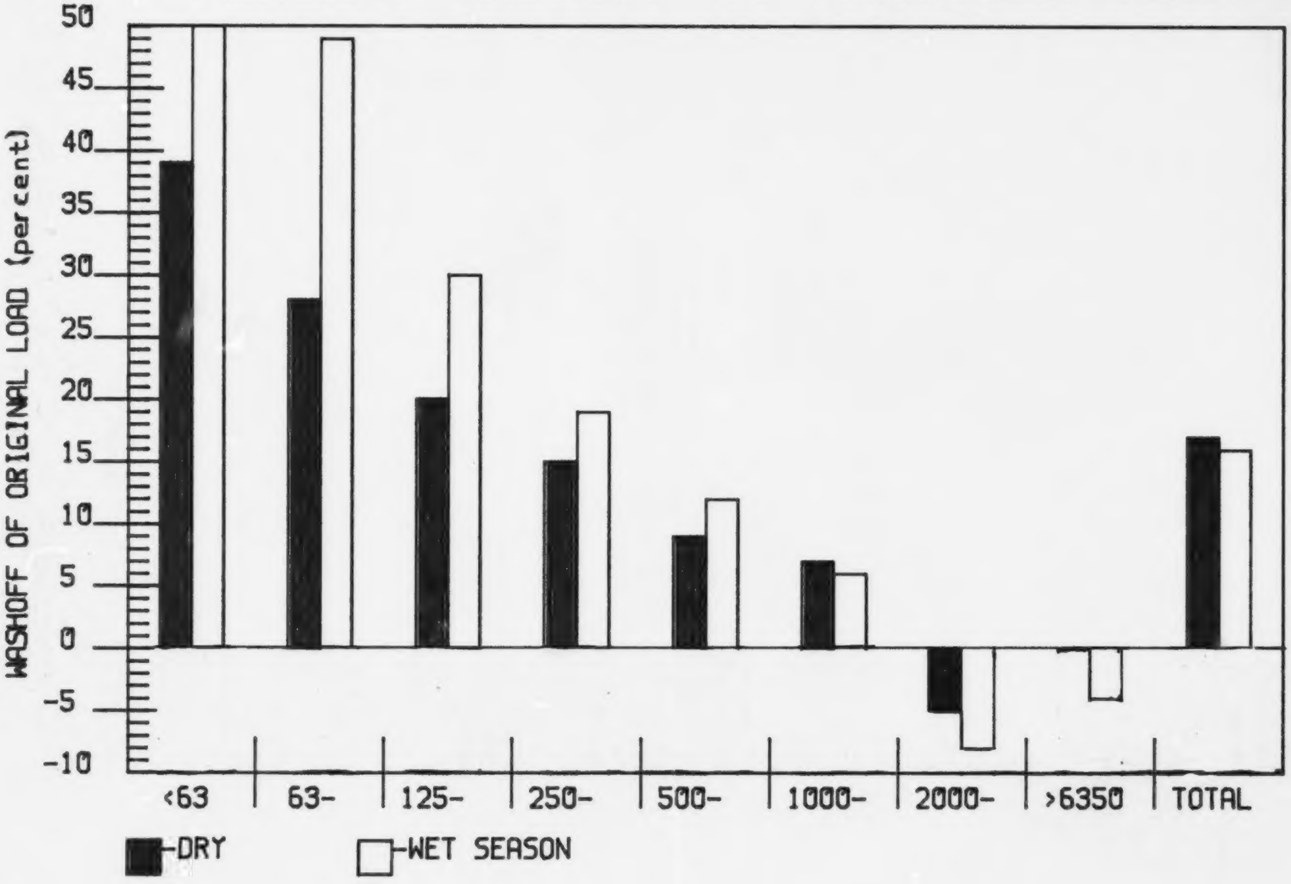

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FIGURE 9-6

WASHOFF SIZE DISTRIBUTION

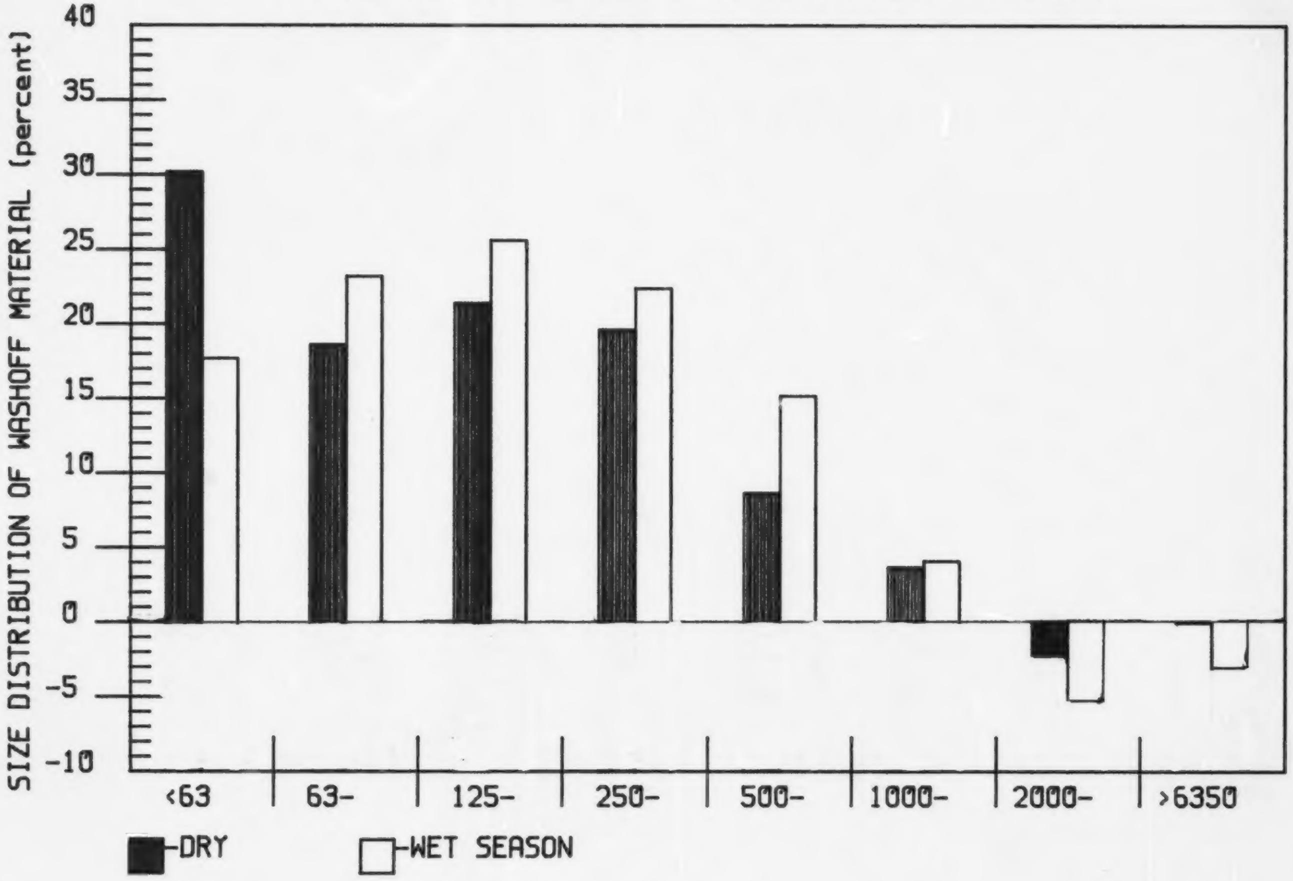

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FIGURE 9-7

LAKE HILLS STREET DIRT WASHOFF

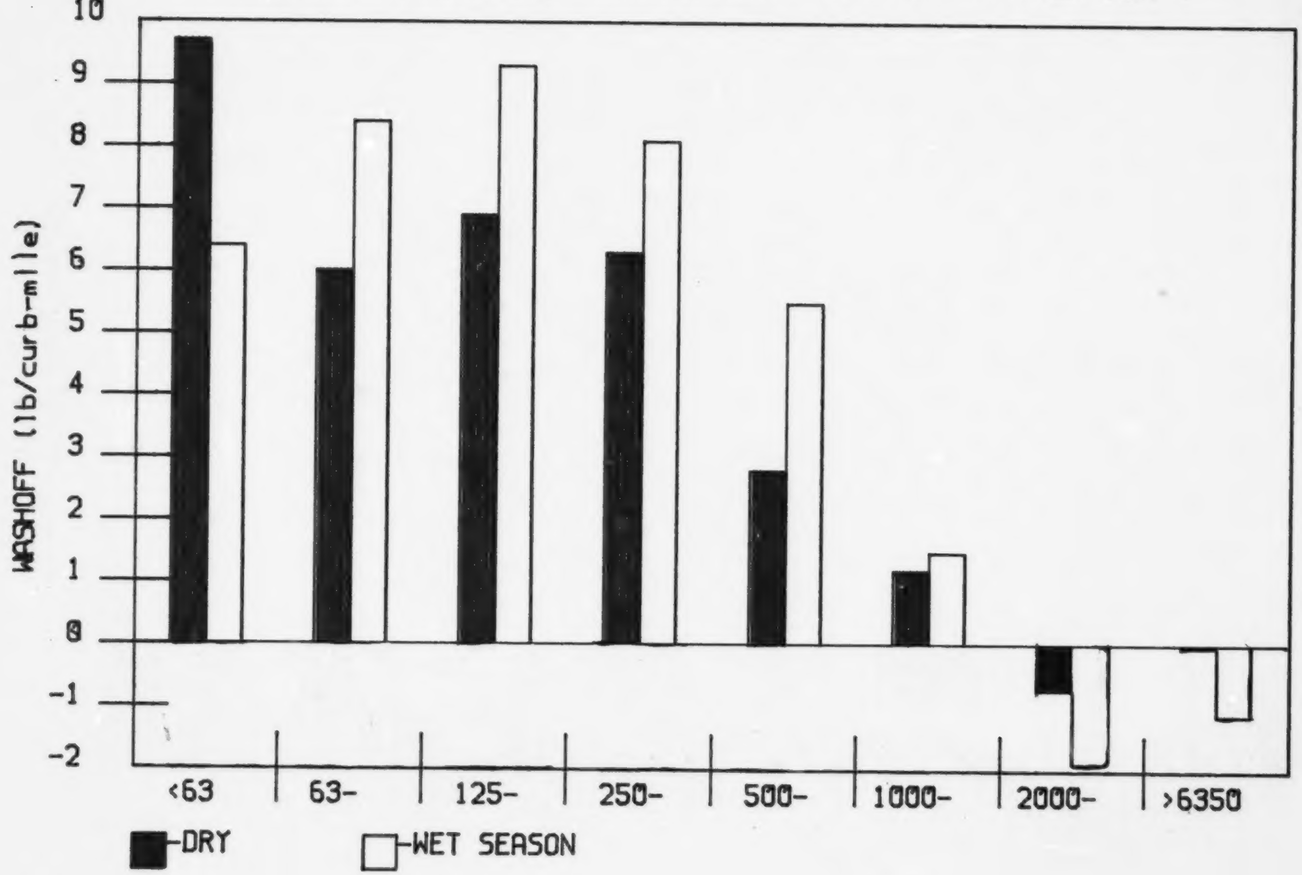

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Table 9-4. ESTIMATED WASHOFF OF STREET SURFACE POLLUTANTS (PERCENT)

	Median Particle Size of Washoff (Microns)	Total Solids	COD	TKN	TP	Pb	Zn
Surrey Downs	190	16%	15	19	16	22	21
108th Street	380	9	10	15	7	18	11
Westwood Homes Rd.	190	13	10	15	13	20	16
Lake Hills	160	18	16	20	19	25	23
148th Avenue, S.E.	220	15	12	15	15	21	21
Average:	230	14	13	17	14	21	18

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removed for the rains that were observed during these tests. The percentage is about the same, or slightly less, for COD and total phosphorus, while it is slightly more for total Kjeldahl nitrogen and zinc. The washoff percentage is substantially greater for lead because of the greater abundance of lead in the smaller particle size ranges. The 108th Street area had much smaller washoffs than any of the other sites, probably because of the greater abundance of larger sized particles on that street. Westwood Homes Road also had smaller washoffs, again because of the larger particle sizes found there.

RUNOFF WATER QUALITY CONCENTRATIONS AND YIELDS DURING PERIODS OF DIFFERENT STREET CLEANING ACTIVITIES

Figures B-24 through B-31 are simple plots relating observed storm runoff concentrations as a function of the total rain. These figures show this information for the two different study sites and for the wet and dry seasons separately. The two symbols on the plots represent periods of time when streets were not cleaned and when the streets were intensively cleaned. These are similar to the figures shown in Section 6, except that these plots are separated by periods of different street cleanliness. Again, the highest concentrations are generally associated with the small rain volumes. However, many more data points are available for the smaller rain events and if additional data were available for the larger events, then a greater spread in data may have occurred.

The lowest concentrations for any rain event are many times associated with periods of time when the streets were not being cleaned. Increased concentrations during periods of intensive street cleaning may be associated with loss of armoring. Sutherland (1982) states that bed armoring occurs when large stable particles rest upon and pin smaller unstable particles that would otherwise have been lifted and transported. Since the street cleaner is removing or disturbing a significant portion of these larger particles, the runoff is more efficient in removing the smaller particles that remain. Other activities such as wind, traffic, and local erosion may have the same effect as street cleaning, since they disturb the particle size distribution and magnitude of the accumulation. These other activities will also have the tendency to increase the effectiveness of runoff in removing the smaller particles that remain on the street or were added to the accumulation.

Figures B-32 through B-35 show this same data, but transformed. The total solids and lead loads for each storm are plotted against the observed flows. These plots have their scale on a log basis to more evenly spread out the data. Again, the data is separated by season, study area, and street cleanliness. The even distribution of the data for these plots indicate that regression analyses are possible. Figures 9-10 through 9-14 show the results of these regression analyses. A 95 percent confidence interval is shown representing "concentrations" for periods of street cleaning and periods of no street cleaning. These confidence bands contain 95 percent of the observations for each of these cleaning situations. The total solids figures for Lake Hills and Surrey Downs for the wet and dry seasons (the Surrey Downs dry season is missing due to very few data collected during that period of time) show that the confidence intervals for the two street cleaning

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FIGURE 9-10

TOTAL SOLIDS - Wet Season - Lake Hills

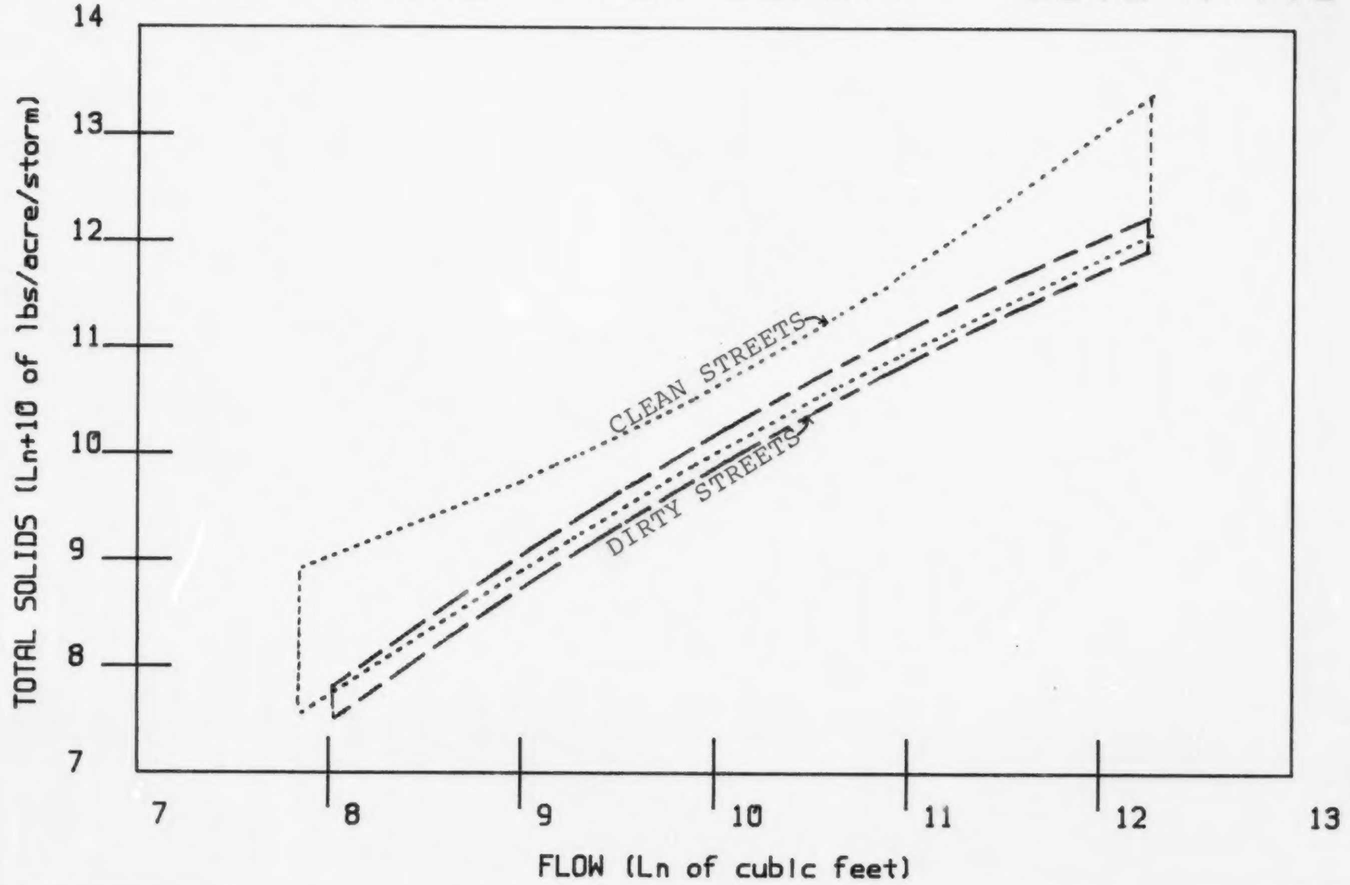

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FIGURE 9-11

TOTAL SOLIDS - Dry Season -Lake Hills

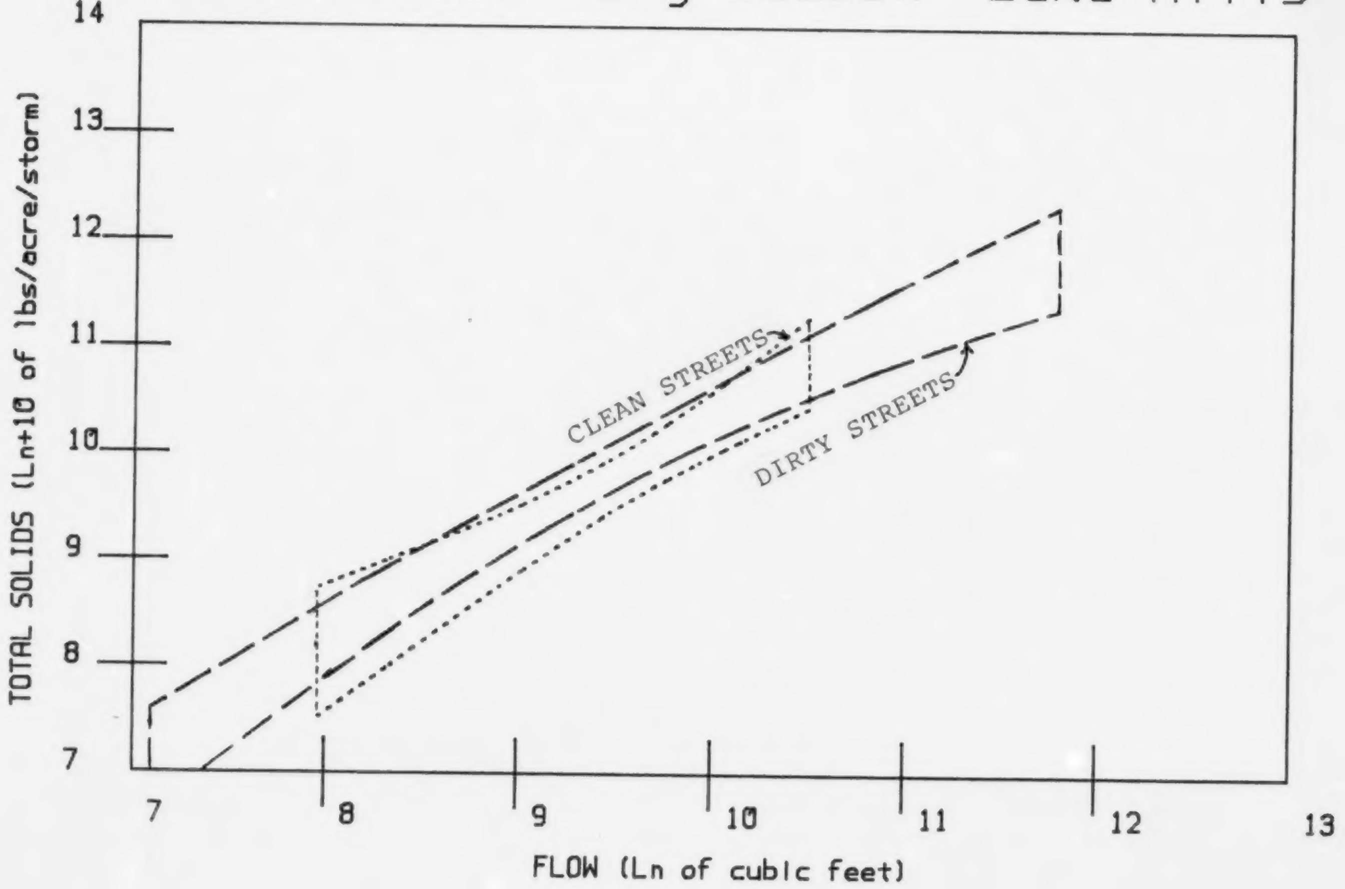

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FIGURE 9-12A

TOTAL SOLIDS - Wet Season - Surrey Downs

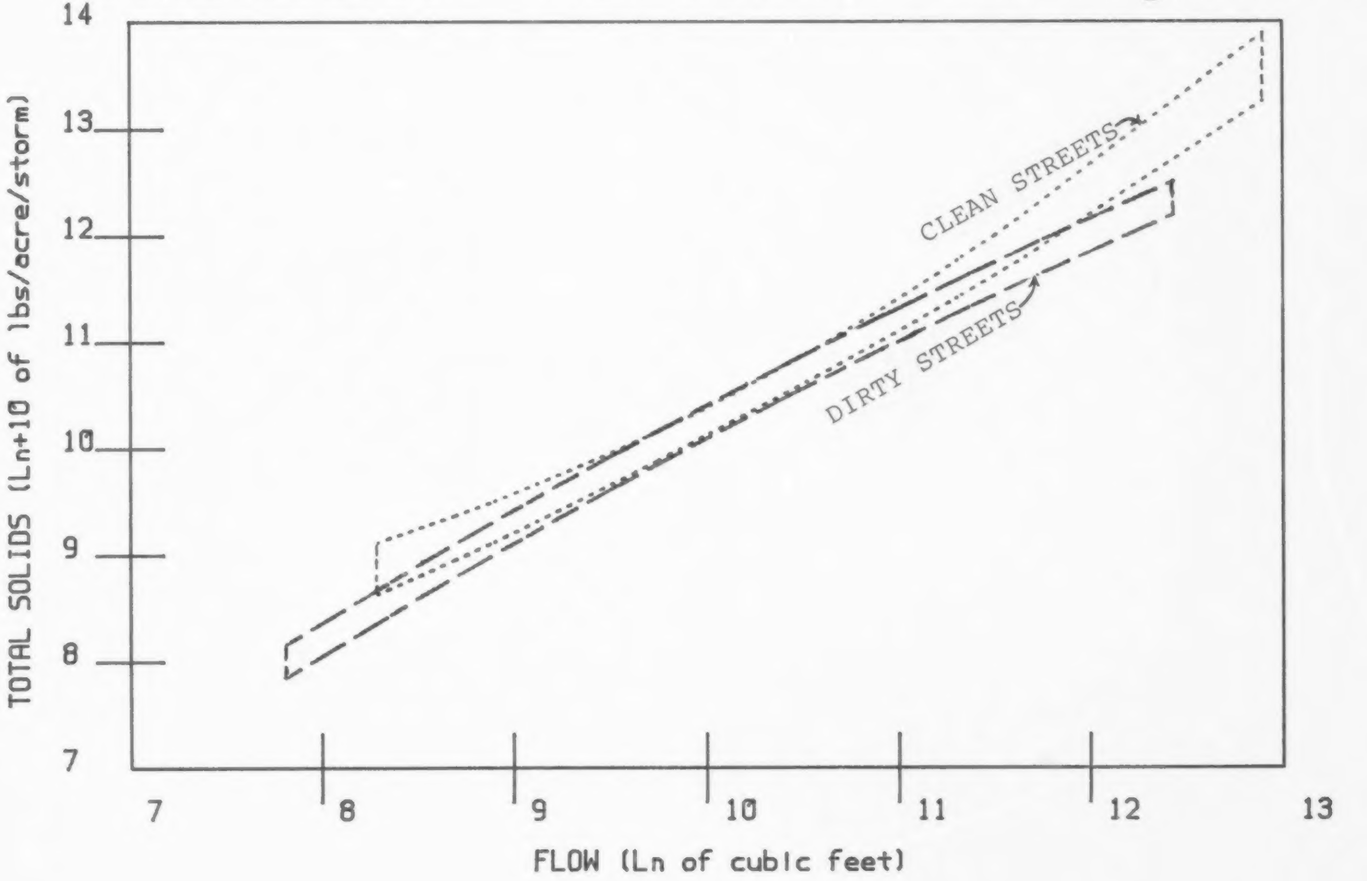


FIGURE 9-12B

LEAD - Wet Season - Lake Hills

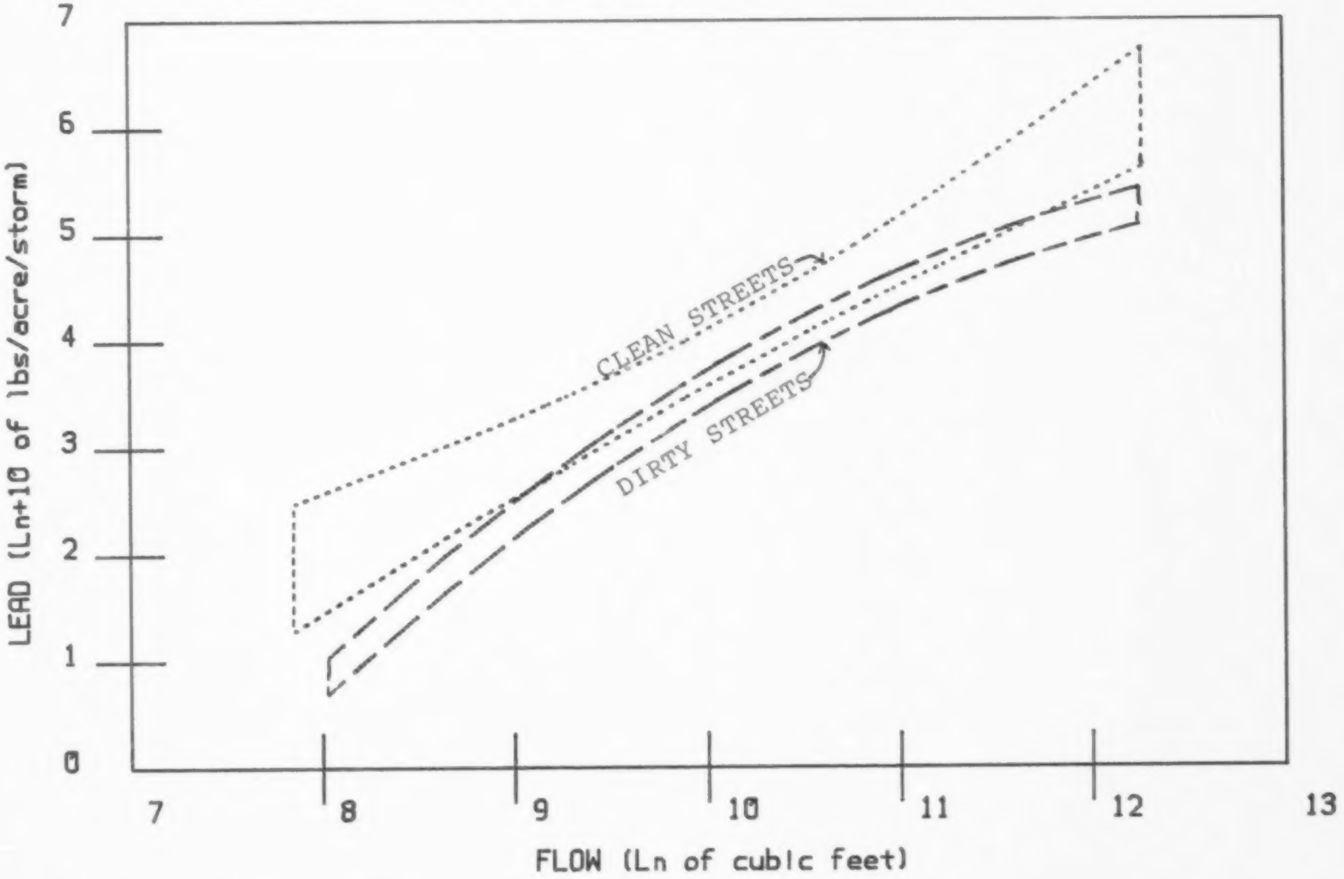


FIGURE 9-13

LEAD - Dry Season - Lake Hills

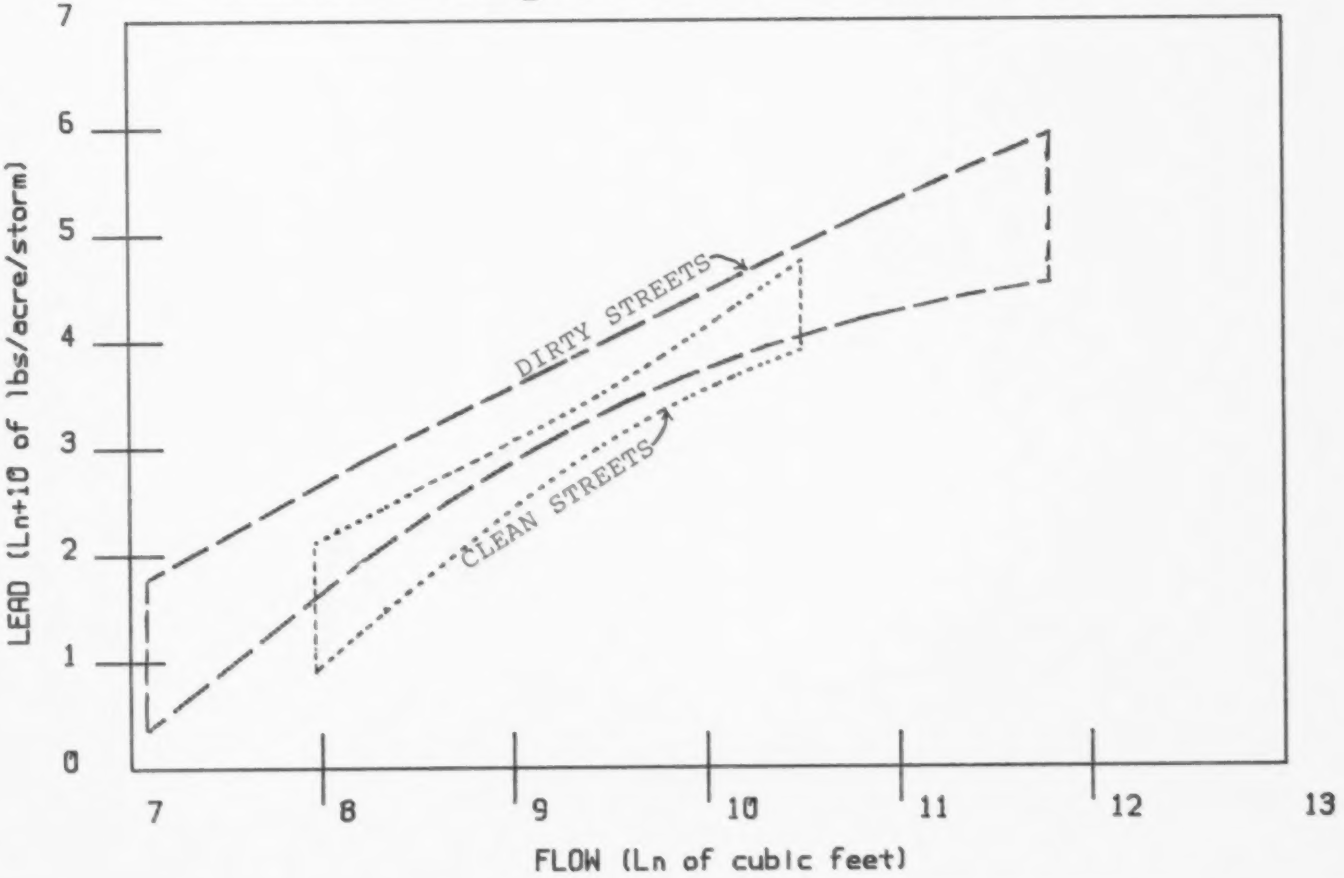
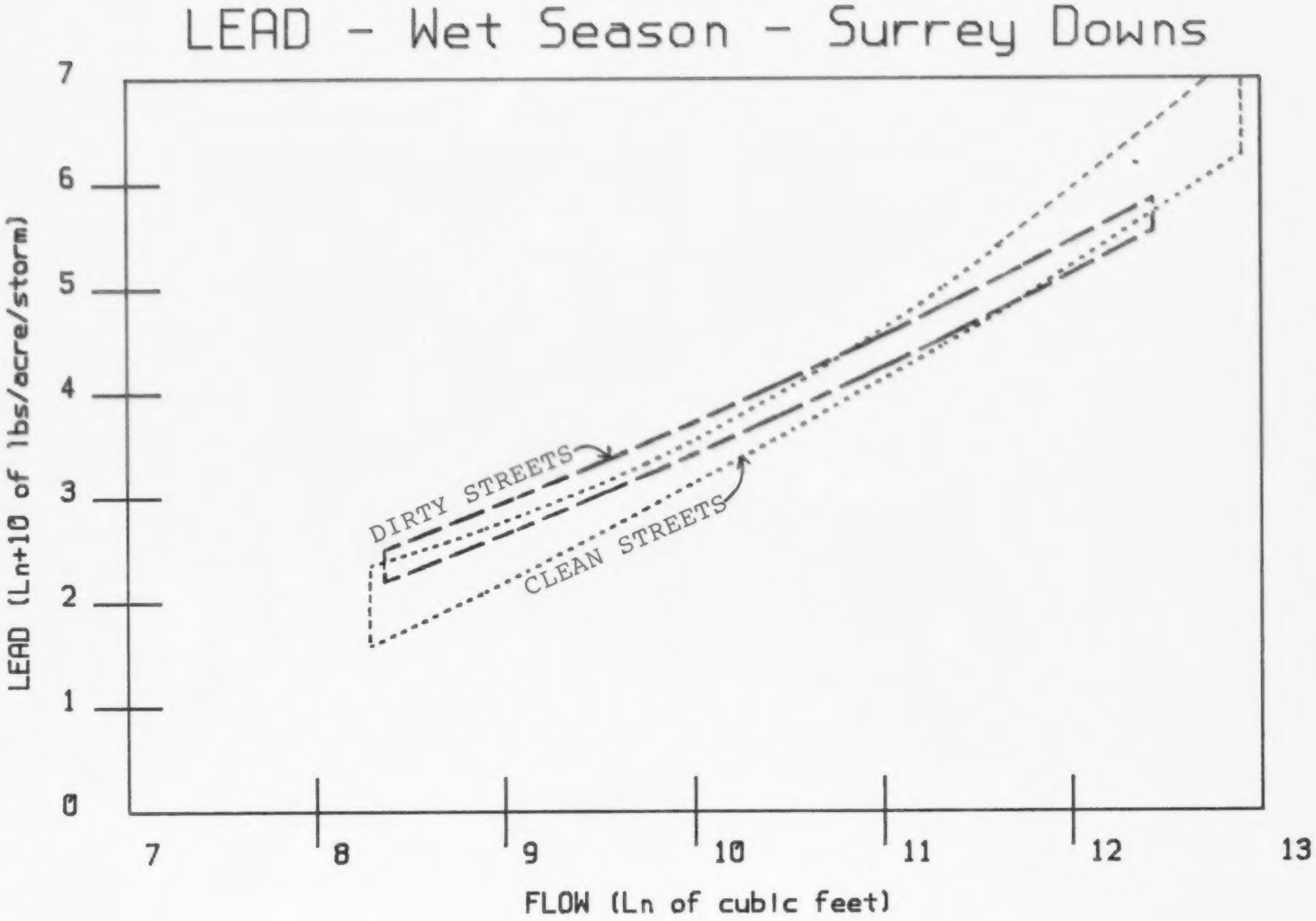


FIGURE 9-14


LEAD - Wet Season - Surrey Downs
LEAD (Ln+10 of lbs/acre/storm)
0
1
2
3
4
5
6
7
FLOW (Ln of cubic feet)
7
8
9
10
11
12
13
DIRTY STREETS
CLEAN STREETS

situations are not distinct and overlap through much of the data ranges. Figures 9-12 and 9-14 are for lead and also show substantial overlap of the confidence bands for clean and dirty street conditions. There is a somewhat greater separation in the confidence bands for lead than there is for total solids. However, they are not completely separated and significant differences (at the 95 percent confidence level) cannot be considered for the two different street cleaning periods over the complete range of flow conditions. The estimated confidence intervals that may correspond to separate confidence bands for the lead analyses are at about the 60 percent level, which is very low. During the Lake Hills wet season, the dirty street surface conditions sometimes resulted in a lower runoff yield for constant flows than during clean street surface conditions (possibly due to bed armoring effects discussed previously). During the Lake Hills dry season and during the Surrey Downs wet season, however, the cleaned street surface conditions resulted in typically lower concentrations. Again, the confidence level of these conclusions is very poor.

RELATIONSHIPS BETWEEN STREET LOAD, RUNOFF YIELD, AND RUNOFF VOLUMES

Preliminary analyses of the Bellevue runoff yield and street surface loading data were performed in the first annual report (Pitt, et al, 1981). This early data analysis effort included plotting the ratio of street surface load to runoff yield as a function of runoff volume. These early efforts were successful as the regression coefficients were quite high (approaching 0.95). The ratios were high (several hundred) for low runoff volumes (less than 0.1 inch, or 2.5 mm of runoff) and then decreased rapidly with increasing runoff volumes. It was thought that these plots showed the sensitivity of runoff yields to street surface loadings. During low runoff volumes, the amount of material on the street before the rain was many times greater than the total runoff yield observed. For large runoff, however, the initial street surface loading values were fairly close to the total runoff yield for such constituents as lead, zinc, and COD, but was much smaller than the runoff yield for nutrients. This conclusion made sense when recognizing the washoff processes in an urban area. The small rain volumes are only capable of removing the material from the directly connected impervious areas, as the rain intensity is only large enough to dislodge the materials and flush them along the street surface. As the rain and runoff volumes increase, all of the street surface material may have been removed, but additional materials from adjacent areas were washed onto the streets and drainage systems through erosion processes. During very large rains, the erosion materials would be much greater than the quantity of street surface loadings removed.

Similar observations relating the street load to runoff yield ratio versus runoff volume were obtained previously in Castro Valley, California (Pitt and Shawley, 1981). In Castro Valley, more constituents were analyzed, but for fewer rains (a total of about 25 complete data sets were available). In Castro Valley, the regression coefficients were mostly 0.95 or greater, showing very good agreement of the data with this conceptual model. In addition, the relative placement of the curves for the different constituents also satisfied these washoff hypotheses. As expected, lead maintained the highest ratio of initial street surface loads to runoff yields over the

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complete range of runoff volumes when compared to the other constituents. In other words, the lead street loads were quite important when compared to the lead runoff yields for most rains. Following lead in order of decreasing sensitivity were total solids, arsenic, COD, total phosphate, zinc, total Kjeldahl nitrogen, and orthophosphate. This order is probably a fairly accurate order of the importance of street dirt constituents to runoff yields.

Upon reviewing this data analysis procedure, it was determined that spurious self-correlations may be responsible for a large portion of these high regression coefficients. Spurious self-correlations may occur when the dependent parameter contains the independent parameter as part of its definition. An example of this would be relating a parameter having very large values against these same values minus a relatively small, but random, variable value. If the large values were in the range of 1,000 to 10,000, and if the other parameter values were these same large values minus a smaller independent value (say in the range of about 100), then the linear regression coefficient between these two values would be very high. Even if the large and the small parameters were completely independent and random, the regression coefficient could be 0.9 or greater (a very good straight line fit) for this example. The dependent parameter would vary between 90 and 100 percent of the independent parameter. This same problem may occur through other normalization procedures, such as multiplication or division of the independent parameter.

The relationship between the street surface load and runoff yield ratio versus runoff volume was thought to possibly be self-correlated. The runoff yield is the concentration times the runoff volume. Therefore, these relationships are really street surface load divided by concentration times runoff volume, while the independent variable was runoff volume. In order to determine the importance of self-correlation (because the runoff volumes were included as both the independent and as part of the dependent variable) various random number distributions were used as raw data testing these different relationships. Random log-normal distributions representing the typical range of street surface loading values for total solids, runoff concentrations and runoff volumes were selected using a simple computer program. These random distributions were completely independent and uncorrelated. The runoff yield for these random values was calculated by multiplying the concentration times the volume times the appropriate conversion factor. The initial street surface load was multiplied by the total number of curb-miles in the basin to obtain a dimensionless ratio of initial street surface load to runoff total solids yield. This ratio was plotted against the runoff volume, expressed in inches. Figure 9-15 shows this random log-normal distribution. The data scatter pattern is similar to the forms obtained using the real data, but the random data has much more scatter. The upper boundary at the data plots generally represents the shape of the curve determined using real data. The regression coefficients using these random values ranged from about 0.2 for a straight line to a high of about 0.4 for a hyperbolic curve. Other curve forms attempted had regression coefficient values intermediate to these two values.

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FIGURE 9-15

Log-Normal Random Ratio of Loads/Yields

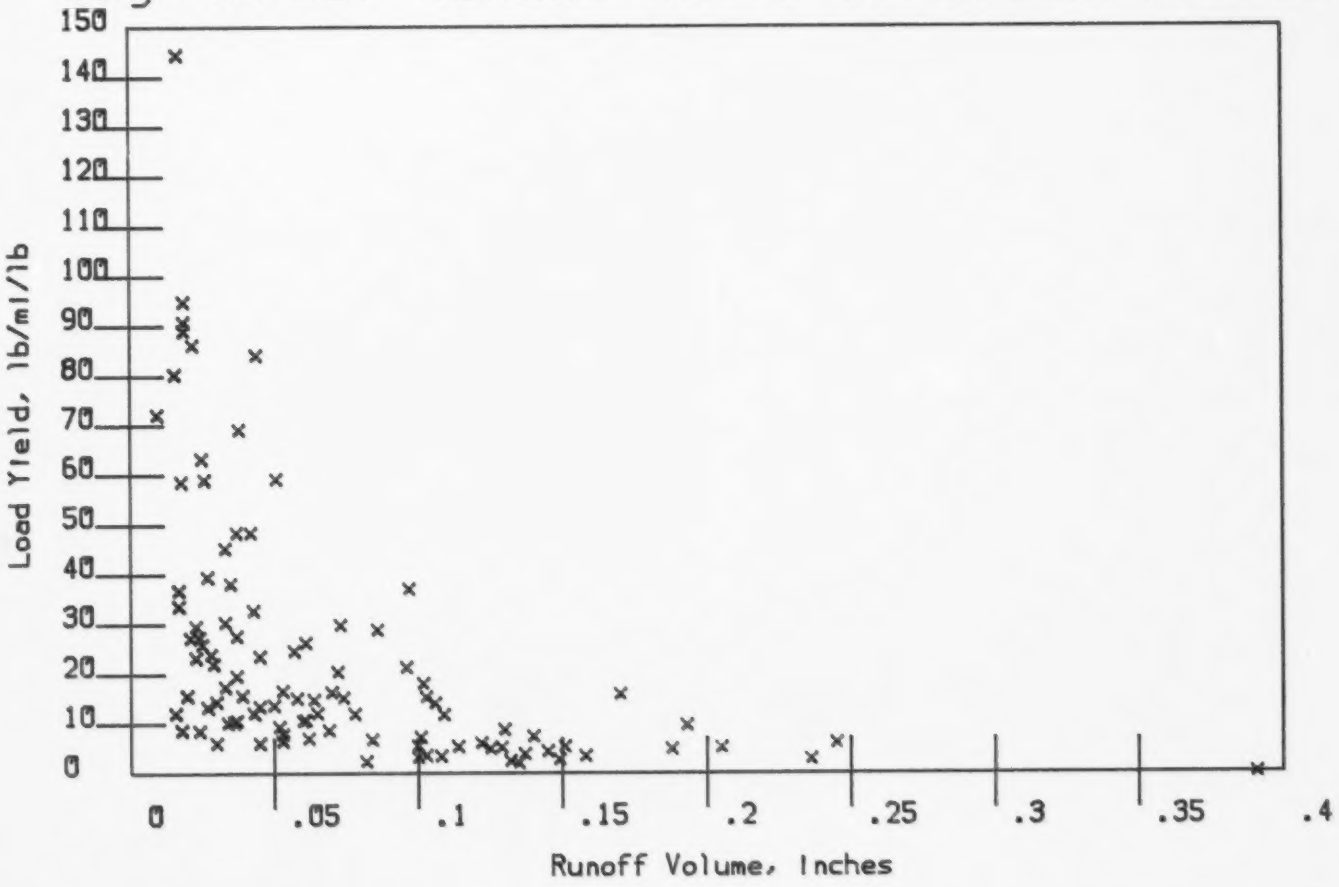

Figure 9-16 shows the ratio of the log-normal random initial street surface loads to the random runoff concentrations plotted against random runoff flows. These value are not self-correlated because the concentration values were directly measured and are not highly correlated with the runoff flows (as discussed in Section 6). The largest regression coefficient using this type of procedure was about 0.18 for a hyperbolic curve. All of the other curve forms had extremely low regression coefficients.

The regression coefficients for these types of data analyses can be assumed to be the minimum values possible without getting into significant spurious self-correlation problems. If the regression coefficients for the real data were substantially greater than the regression coefficients for these random number values, then the calculated values using the real data can be important. As noted earlier, the regression coefficients for the preliminary Bellevue data analyses were somewhat higher than these log normal random number values, while the values using the Castro Valley data were much larger than these values. Therefore, this analysis procedure can be important, but care must be taken in its use and interpretation.

Lake Hills data were used in these analyses because the whole basin was cleaned by the street cleaning equipment. In Surrey Downs, only 3.5 miles (5.6 km) of the 5.5 miles (8.8 km) of street were cleaned and, therefore, street cleaning would have less potential beneficial effects on runoff water quality. Figure 9-17 shows a plot relating the ratio of initial total solids street surface loads to the runoff yield versus the runoff volume. The pattern of the data scatter shown is very similar to the relationships found in the preliminary analyses. The location of the knee of the curve indicates the importance of street surface loadings to runoff yield and occurs at about 0.1 inch (2.5 mm) of runoff. If the knee of the curve is located at a high runoff volume, the street loadings and street contaminant washoffs would be more important over a wider range of rain and runoff conditions than for a contaminant whose curve knee occurs at a lower runoff volume. There is quite a bit of scatter beneath the upper boundary of the data points, but the scatter is much less than was shown on the random data plot of Figure 9-15.

Figure 9-18 relates the ratio of the observed total solids street washoff to the runoff yield against the runoff volume. The pattern of the data scatter is quite similar to Figure 9-17, with the knee of the curve somewhat less than 0.1 inch (2.5 mm) of runoff. Figure 9-19 relates the ratio of street surface washoff of lead to runoff yield against the runoff volumes. Figure 9-20 relates the ratio of total solids street load to runoff concentration against the runoff volume. In this case, the only relationship observed is a constant value for the ratio of about one to two lbs/curb-mile (0.3 to 0.6 g/curb-meter) per mg/l. This ratio is somewhat constant over the complete range of runoff volumes, but some very high values intermittently occurred. This constant relationship was further investigated in Figure 9-21 which relates the initial total solids load on the street to the observed runoff concentrations. No apparent relationship was observed for this case.

Figures B-36 through B-39 relate the ratio of street surface washoff to runoff yield values for total Kjeldahl nitrogen, COD, phosphorus, and zinc against the runoff volumes. The patterns of all of these scatterplots are

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FIGURE 9-16

Log-Normal Random Ratio of Loads/Conc.

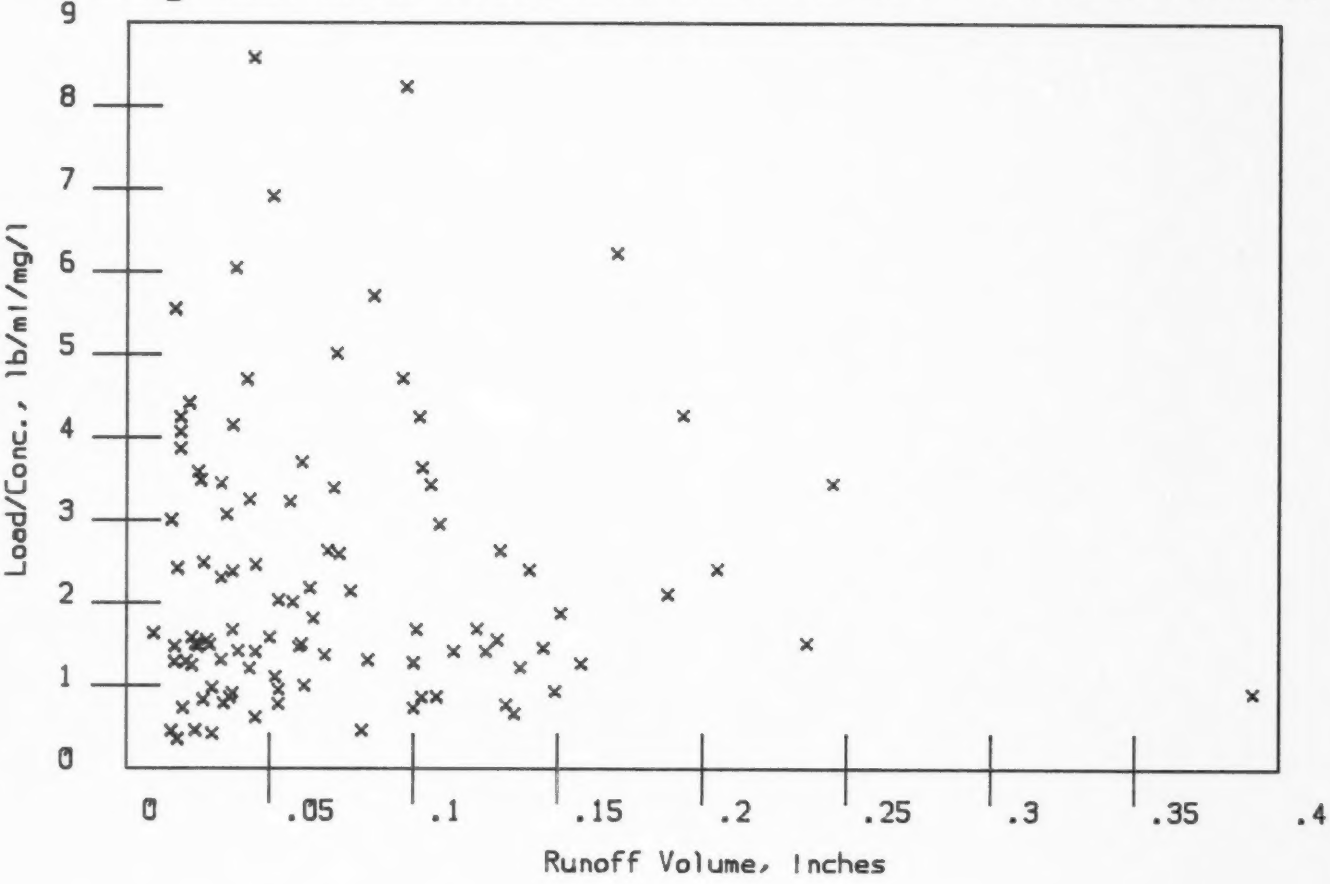


FIGURE 9-17

TOTAL SOLIDS LOAD/YIELD FOR LAKE HILLS

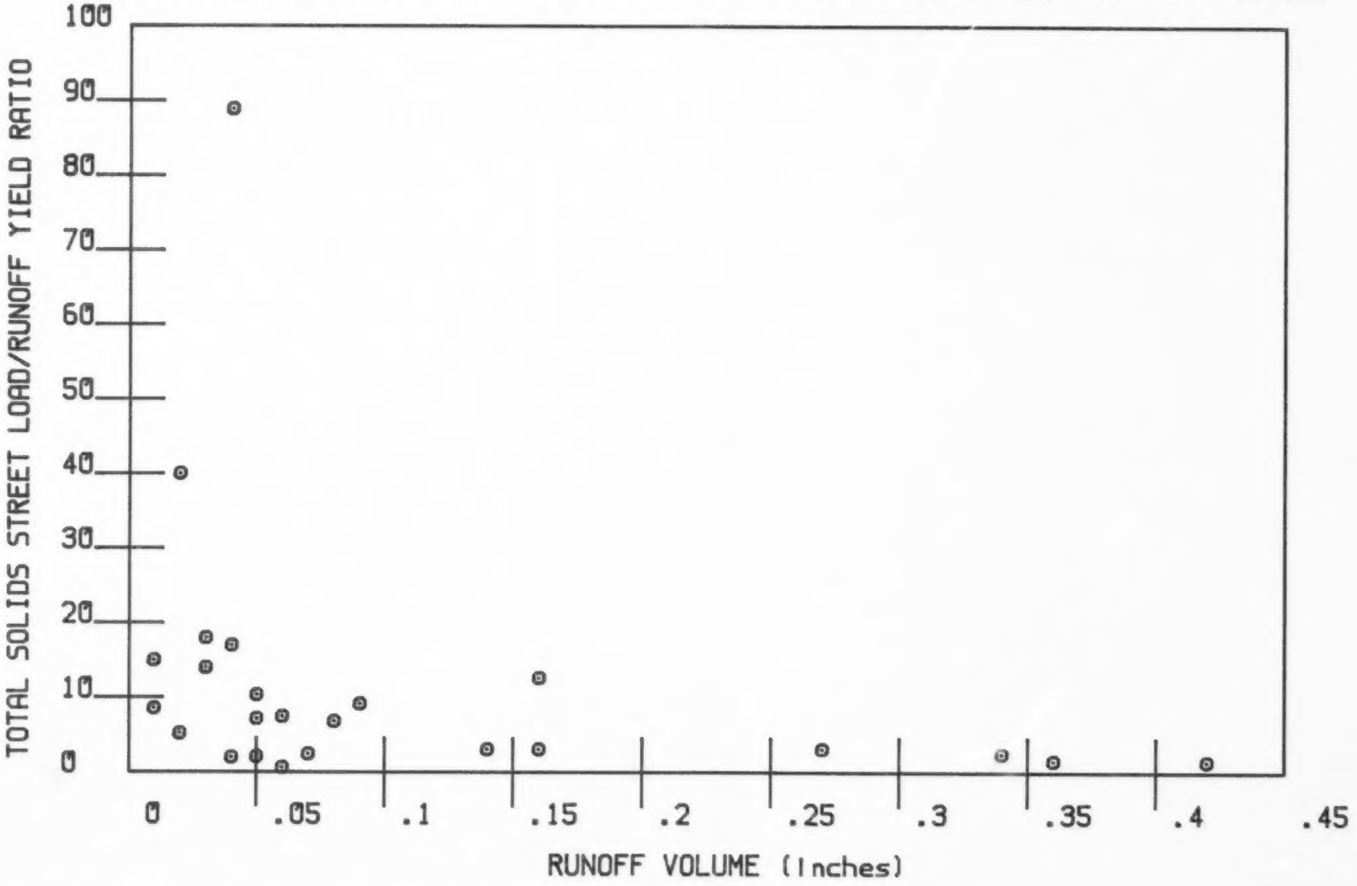


FIGURE 9-18

TOTAL SOLIDS WASHOFF/YIELD .

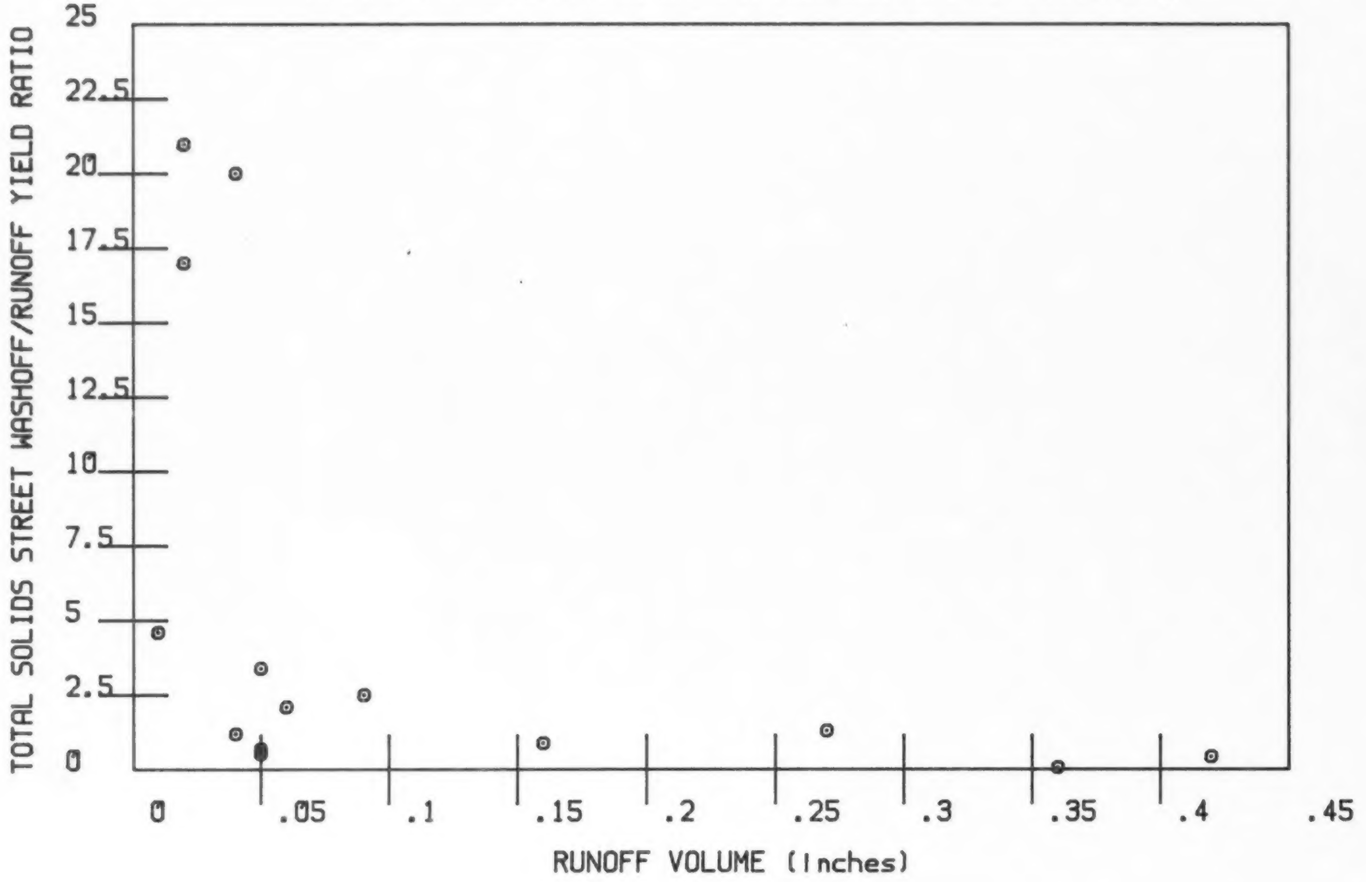


FIGURE 9-19

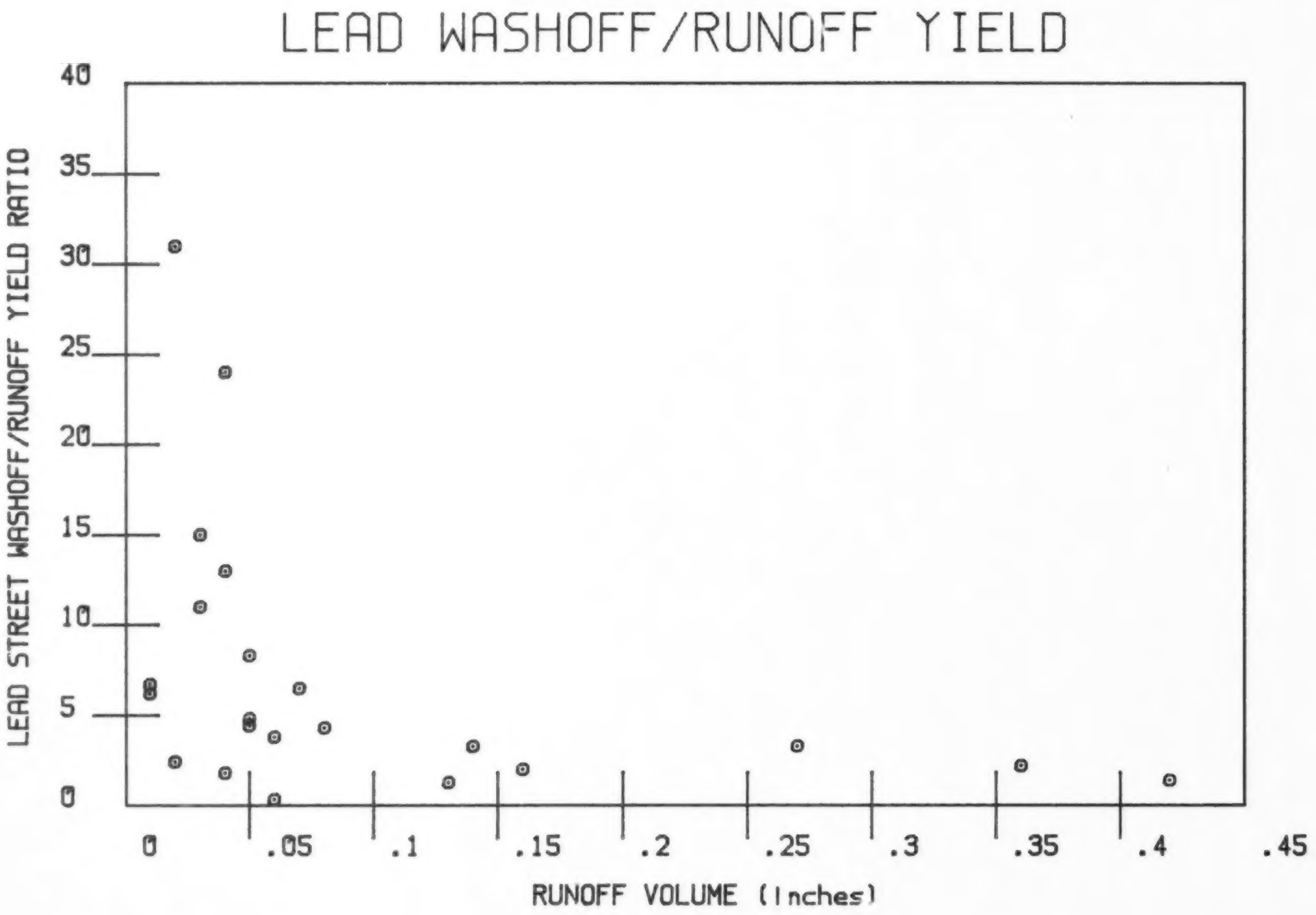

LEAD WASHOFF/RUNOFF YIELD
LEAD STREET WASHOFF/RUNOFF YIELD RATIO
0
5
10
15
20
25
30
35
40
0
.05
.1
.15
.2
.25
.3
.35
.4
.45
RUNOFF VOLUME (Inches)

FIGURE 9-20

TOTAL SOLIDS STREET LOAD/RUNOFF CONC RATIO

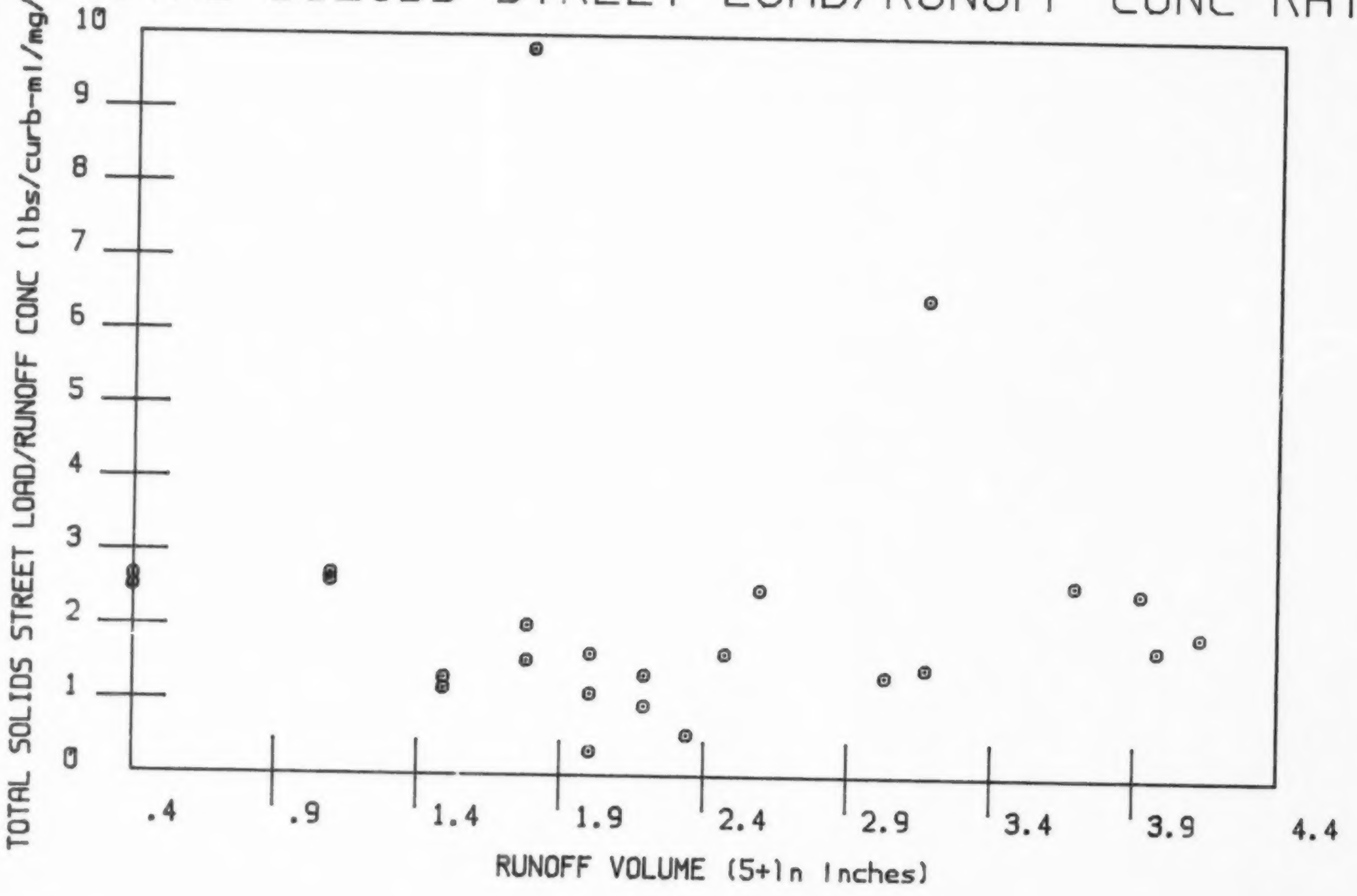
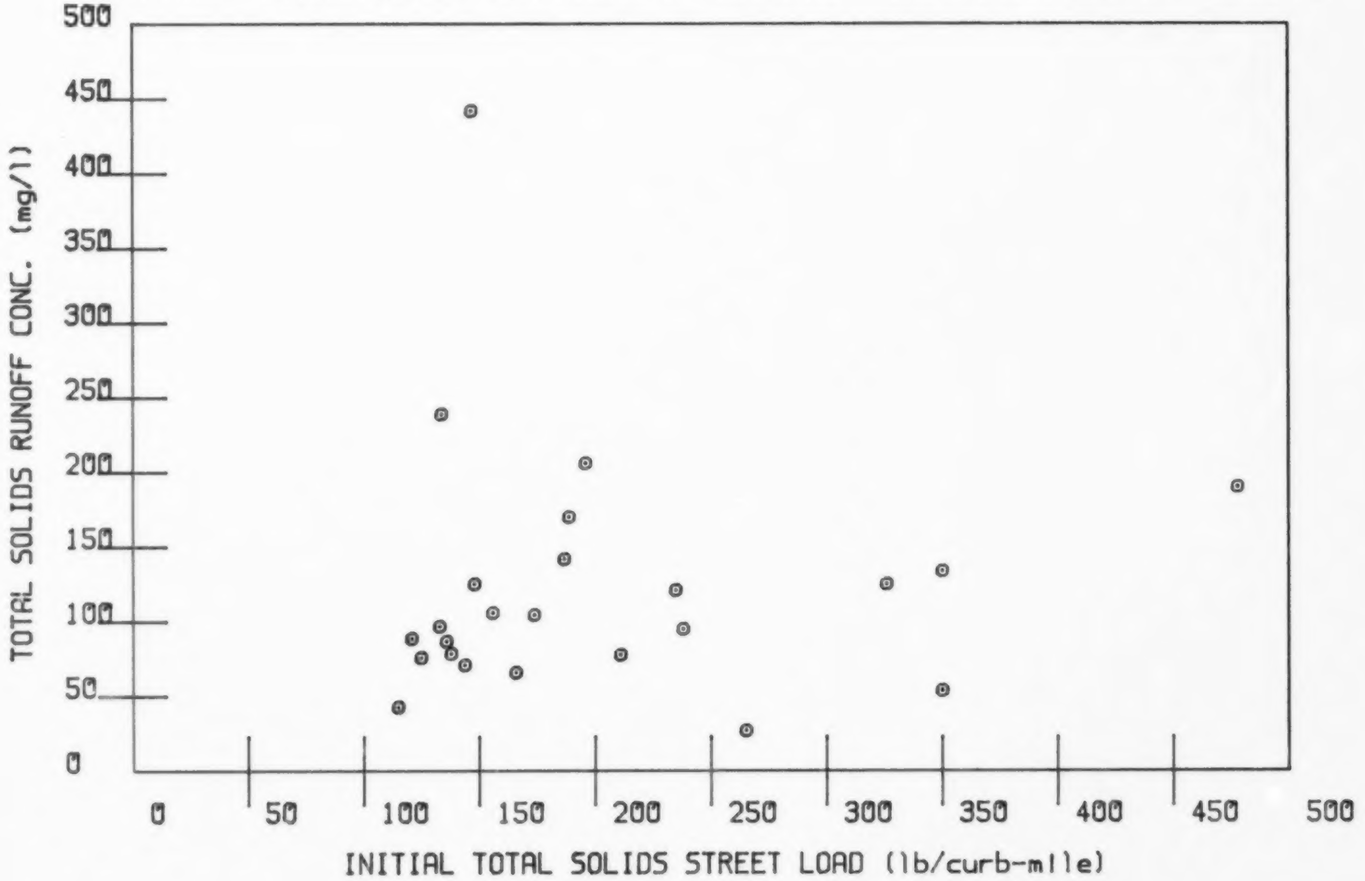


FIGURE 9-21

TOTAL SOLIDS STREET LOAD VS RUNOFF CONC



quite similar, but the maximum ratios of street surface washoff to runoff yield varies substantially for each constituent. Additional analyses relating the ratios of street surface loads to runoff concentration against ln transformed runoff volumes were made for all constituents. In all cases, a nearly straight line was observed, with different approximate ratios for each constituent. Corresponding plots of street loads versus runoff concentrations, however, never showed a significant relationship for any of the constituents.

COMPARISONS OF OBSERVED RUNOFF CONCENTRATIONS IN THE TWO TEST BASINS

A major advantage of using test and control basins is the ability to compare the runoff quality during different test conditions in the different basins. Intensive street cleaning operations were rotated, so that street cleaning occurred in both basins during wet and dry seasons, while the other basin did not have any street cleaning. In addition, about two months during both the dry and the wet seasons did not have any street cleaning in either basin. The period of time with no street cleaning was used to "calibrate" the basins. Urban runoff conditions at the two sites during these no cleaning periods were compared to determine "natural" differences and variations.

Table 9-5 identifies the storms for the period of time when street cleaning was not conducted in either basin. Also shown on this table are the rain totals that occurred in each basin for these calibration storms, along with the ratio of rain totals for the two basins. Several other rains also occurred during this time period that were completely monitored, but the differences in rain volumes at the two sites were very large. This was quite common with the smallest rain events as described previously in Section 4. Those storms with quite different rain volumes for the same rain period were eliminated from these analyses. This table shows that 20 storms were completely monitored during periods of no street cleaning in either basin. The average rain in both basins was about 0.45 inch (11 mm), or about twice the volume of the average rains during the complete study period. The range of rains during this calibration period were from about 0.04 inch (1 mm) to a high of about 1.25 inches (32 mm). These calibration rains, however, were weighed more towards the larger rain events than the typical distribution of rains. The smaller rain events experienced much greater variations in observed rainfall and runoff volumes and more of the smaller events were eliminated from the analyses.

Table 9-6 summarizes the storm information during periods when intensive street cleaning was conducted in Lake Hills, while no street cleaning occurred in Surrey Downs. The 27 monitored storms were divided about evenly between the wet and dry seasons. Again, the average rain volume during this period was quite a bit larger than the average rain volume over the complete period of testing. Table 9-7 is a similar listing, showing rain data when intensive street cleaning was conducted in Surrey Downs, but no street cleaning was conducted in Lake Hills. Almost all of these storms occurred during the wet season because of early sampling equipment problems in Surrey Downs as described in Sections 5 and 6.

Table 9.5. COMPLETE STORM DATA DURING PERIODS OF NO STREET CLEANING IN EITHER BASIN (CALIBRATION DATA)

Storm Date	Season	Storm Number	Lake Hills Rain (in)	Surrey Downs Rain (in)	Rain Ratio (LH/SD)
7/11/80	dry	21	0.28	0.22	1.27
7/14	dry	22	0.15	0.15	1.00
8/26	dry	25	0.04	0.08	0.50
8/27	dry	26/26+27(1)	0.43	0.55	0.78
9/1	dry	28+29/28	0.52	0.50	1.04
9/6	dry	30	0.23	0.27	0.85
9/12	dry	31	0.12	0.08	1.50
9/13	dry	32	0.16	0.14	1.14
11/28	wet	51	0.83	0.86	0.97
12/14	wet	55	0.17	0.11	1.55
12/20	wet	56	0.43	0.43	1.00
12/24	wet	58	0.26	0.26	1.00
12/24	wet	59	0.44	0.51	0.86
12/26	wet	61	0.32	0.34	0.94
12/29	wet	62	1.11	1.14	0.97
7/6/81	dry	114	0.64	0.53	1.21
7/13	dry	116	1.25	1.17	1.07
1/10/82	wet	156	0.35	0.30	1.17
1/15	wet	158	0.98	1.10	0.89
1/17	wet	159	0.18	0.16	1.13
		average:	0.45	0.45	1.04
		minimum:	0.04	0.08	0.50
		maximum:	1.25	1.17	1.55
		N = 20			

(1) LH/SD storm numbers, if different

Table 9-6. COMPLETE STORM DATA DURING PERIODS OF STREET CLEANING IN LAKE HILLS ONLY

Storm Date	Season	Storm Number	Lake Hills Rain (in)	Surrey Downs Rain (in)	Rain Ratio (LH/SD)
9/20/80	dry	34	0.25	0.38	0.66
10/8	wet	37	0.11	0.19	0.58
10/12	wet	38	0.16	0.12	1.33
10/24	wet	39	0.17	0.16	1.06
10/31	wet	40+41/40(1)	0.74	0.74	1.00
11/1	wet	42	0.36	0.29	1.24
11/3	wet	43	0.52	0.60	0.87
11/8	wet	45	0.41	0.43	0.95
11/14	wet	46	0.15	0.12	1.25
11/19	wet	47	0.19	0.21	0.91
11/20	wet	48	1.55	1.66	0.93
1/17/81	wet	63	0.15	0.22	0.68
1/28	wet	69	0.60	0.63	0.95
2/11	wet	70+71/70	1.00	0.91	1.10
2/13	wet	72	0.24	0.20	1.20
3/24	dry	85	0.21	0.26	0.81
3/28	dry	86	0.14	0.18	0.78
4/5	dry	89	0.18	0.16	1.13
4/6	dry	90	0.34	0.38	0.90
4/7	dry	91	0.28	0.22	1.27
4/10	dry	92	0.36	0.30	1.20
4/12	dry	93	0.12	0.13	0.92
4/27	dry	97	0.53	0.47	1.13
5/24	dry	105	0.36	0.31	1.16
6/12	dry	109	0.28	0.23	1.22
6/12	dry	110	0.21	0.33	0.64
6/30	dry	113	0.33	0.25	1.32
		average:	0.37	0.37	1.01
		minimum:	0.11	0.12	0.58
		maximum:	1.55	1.66	1.33
		N = 27			

---

(1) LH/SD storm numbers, if different

Table 9-7. COMPLETE STORM DATA DURING PERIODS OF STREET CLEANING IN SURREY DOWNS ONLY

Storm Date	Season	Storm Number	Lake Hills Rain (in)	Surrey Downs Rain (in)	Rain Ratio (LH/SD)
4/18/80	dry	8	1.33	1.18	1.23
10/8/81	wet	127	0.27	0.24	1.13
10/28	wet	129	0.20	0.17	1.18
10/30	wet	131	0.07	0.09	0.78
11/11	wet	132	1.58	1.50	1.05
11/13	wet	133	0.14	0.11	1.27
11/30	wet	137	0.12	0.14	0.86
12/3	wet	140	0.16	0.19	0.84
12/4	wet	141	1.43	1.27	1.13
12/9	wet	148	0.84	0.78	1.08
12/13	wet	149	0.30	0.36	0.83
12/14	wet	150	0.96	0.87	1.10
12/17	wet	151	0.21	0.29	0.72
12/18	wet	152	0.69	0.79	0.87
12/23	wet	154	0.26	0.27	0.96
		average:	0.57	0.55	1.00
		minimum:	0.07	0.09	0.72
		maximum:	1.58	1.50	1.27
		N = 15			

Figures B-40 through B-43 are scatter plots showing total solids yields and concentration differences in Lake Hills and Surrey Downs for both the dry and wet seasons. During the dry season, only the calibration data and the data when intensive cleaning occurred in Lake Hills are shown. There is a large amount of scatter and statistical tests did not show significant differences in calibration conditions for dry and wet seasons. The observations were fairly evenly distributed over a large range of concentrations and regression analyses were conducted for all of the seasons combined. Figures 9-22 through 9-30 show the results of these regression analyses by plotting 95 percent confidence intervals for the calibration data points; for cleaning in Surrey Downs only, and for cleaning in Lake Hills only. There were no significant differences noted in concentrations over the ranges of data that were common to all three data sets. The confidence intervals overlapped over most of the concentration ranges. Therefore, the confidence that street cleaning in either basin resulted in a significant difference (at the 95 percent level of significance or greater) in runoff concentrations did not occur. In fact, the only constituents where a difference might have occurred are for pH and turbidity. The pH differences are not very meaningful, while the turbidity differences were probably caused by the unusually narrow range in observed turbidity values that occurred during the period when cleaning was conducted in Surrey Downs.

SUMMARY

A large amount of the data analysis effort in this project was directed towards attempting to identify differences in runoff concentrations and yields caused by street cleaning operations. The many statistical procedures described in this section could not identify any significant differences in observed runoff yields or concentrations during periods of intensive street cleaning versus no street cleaning. Very few exceptions were observed, and were probably due to other factors. As noted in Sections 4, 5, and 6, the rainfall characteristics and the resultant runoff volumes create substantial differences in observed conditions. If the runoff volumes varied by large amounts (a difference of at least 25 percent was quite common, especially for the smaller rains), then resultant runoff conditions could vary by much more than the differences caused by street cleaning.

Section 6 estimated the contributions of street surface particulates to runoff yields. In almost all cases, street dirt was expected to contribute less than about 25 percent of the runoff yields over the rain conditions observed in Bellevue. The one exception was lead, where street surfaces could contribute about half of the total runoff lead yield. If street cleaning operations could control a substantial fraction of the street surface particulates that could be washed off the street surfaces, then a difference in observed runoff conditions may have occurred. However, as described in an early part of this section, rains are most effective in removing particles smaller than several hundred microns in size. These particle sizes contain the largest concentrations of the heavy metals and quite large concentrations of many of the nutrients. As described in the following Section 10, normal street cleaning equipment is not effective in removing the small particle sizes and can only effectively remove the particle sizes greater than several

FIGURE 9-22

TOTAL SOLIDS CONCENTRATION COMPARISIONS

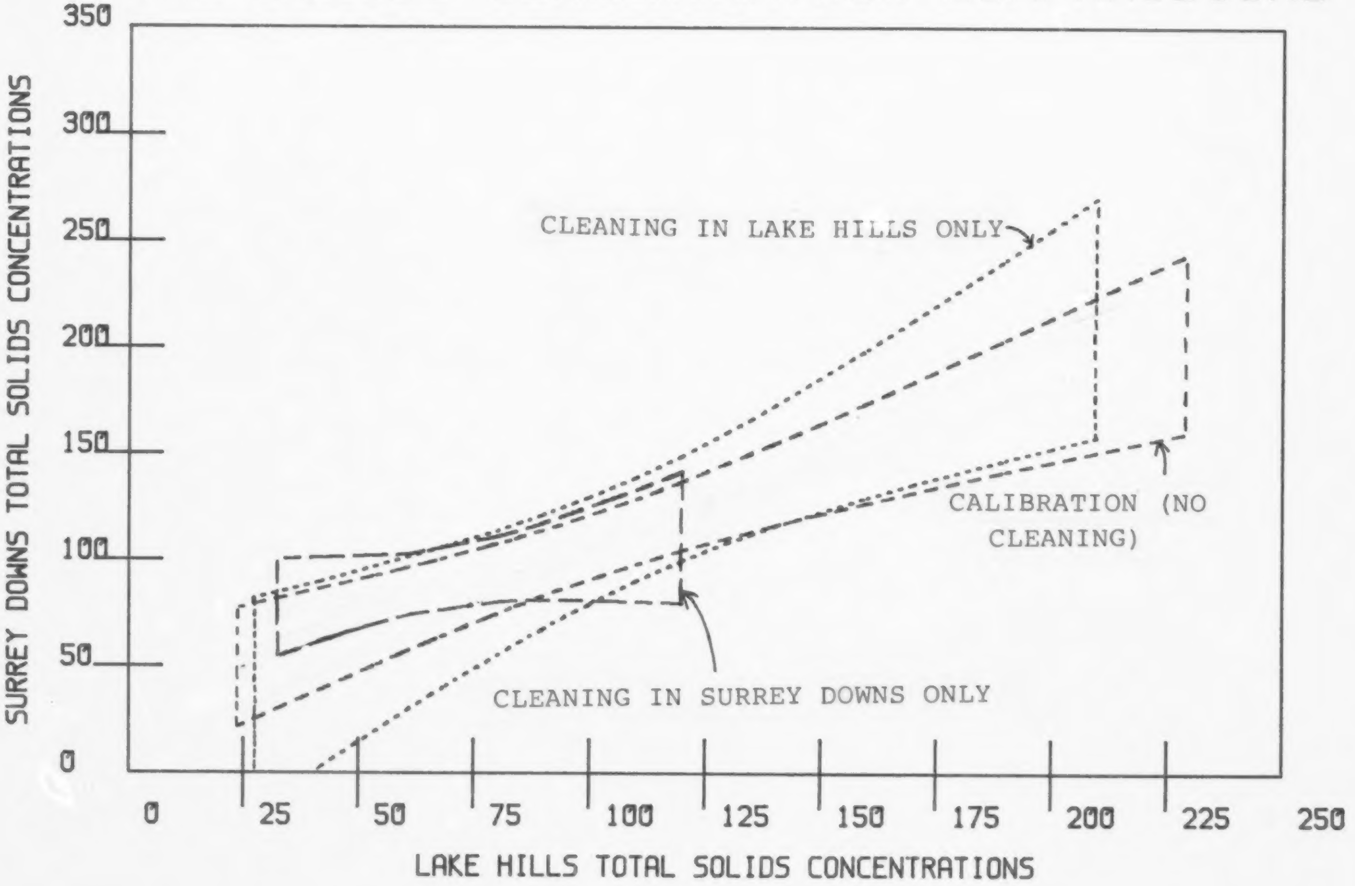


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FIGURE 9-23

TKN CONCENTRATION COMPARISIONS

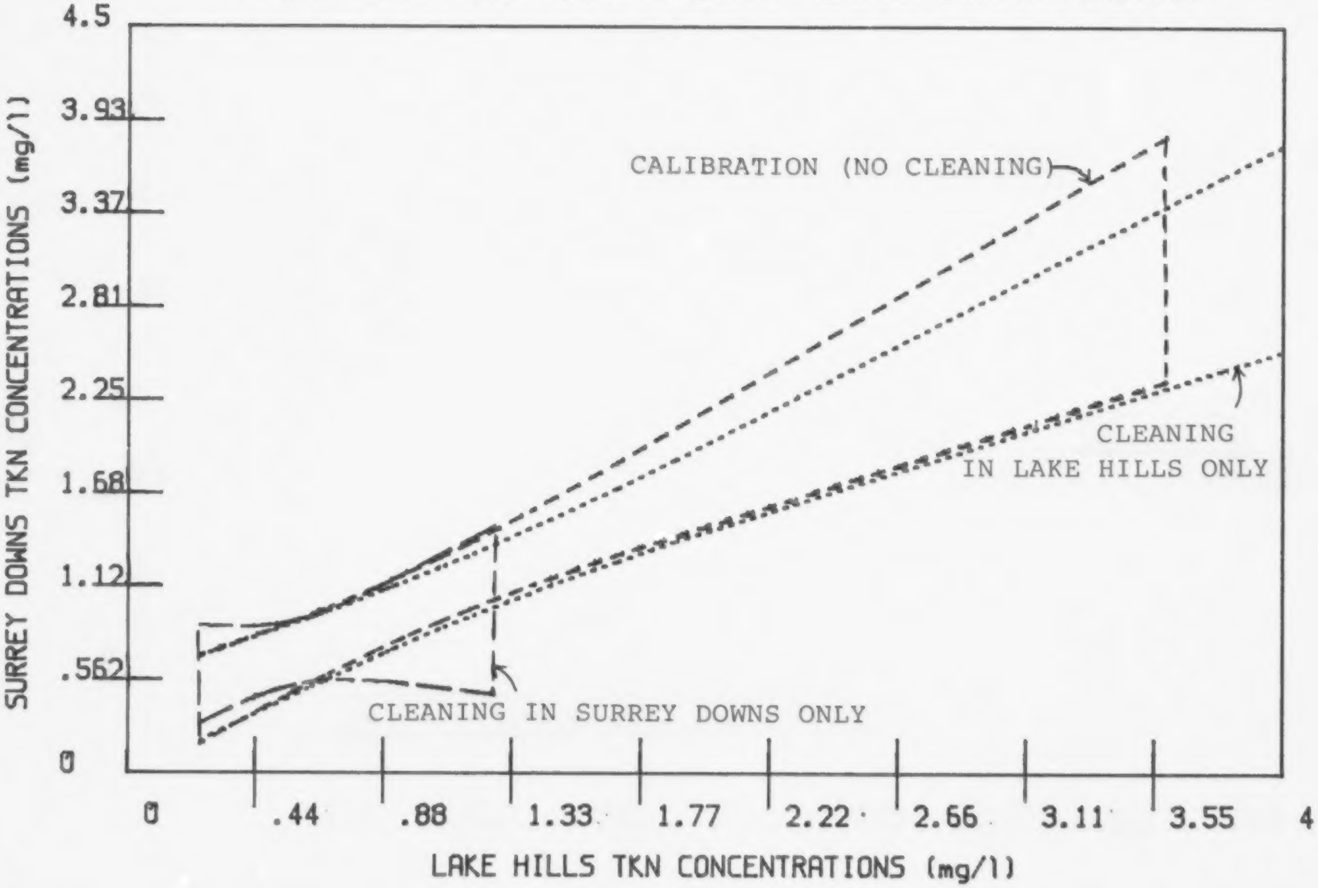

FIGURE 9-24

COD CONCENTRATION COMPARISIONS

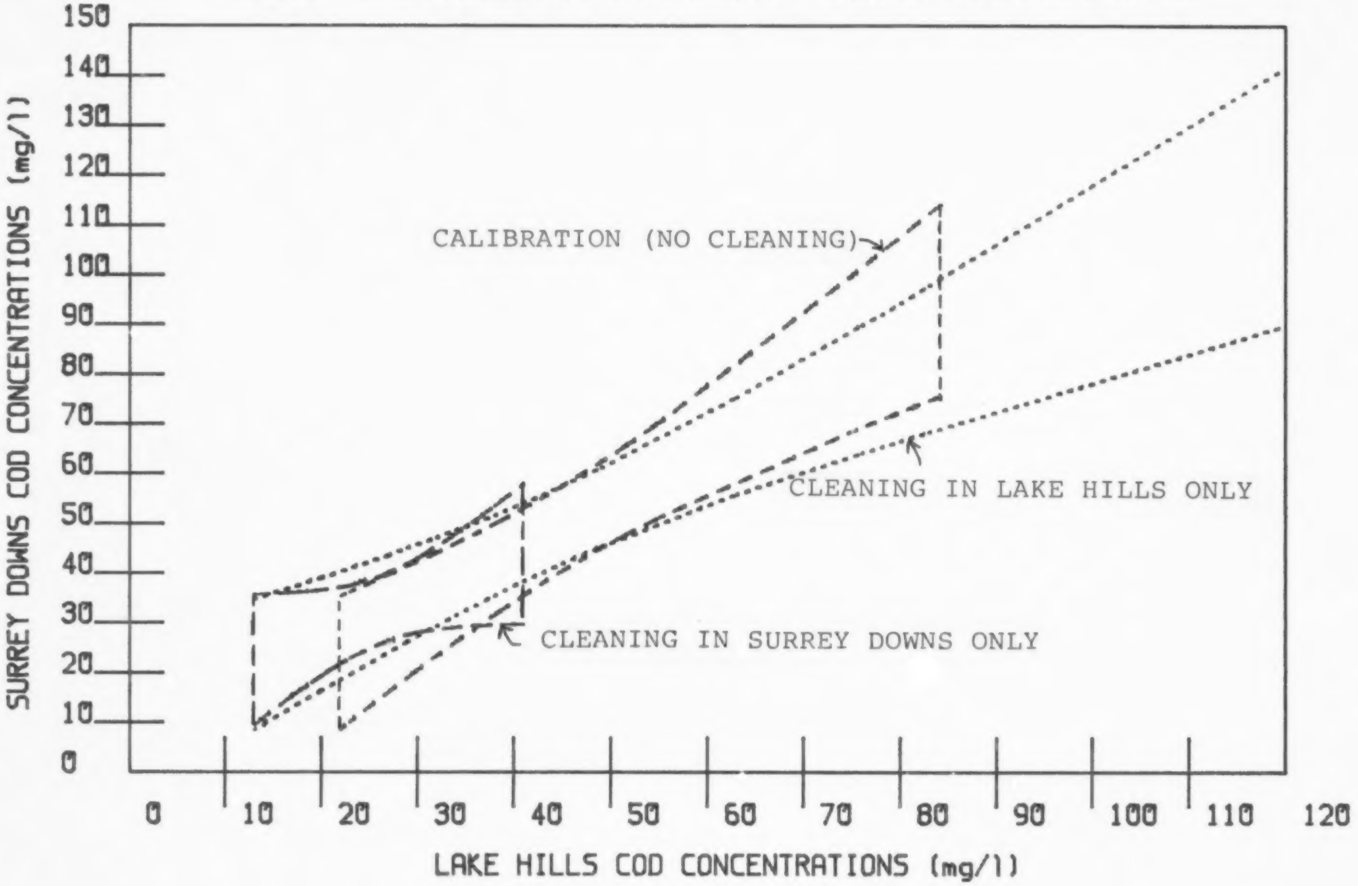

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FIGURE 9-25

PHOSPHORUS CONCENTRATION COMPARISIONS

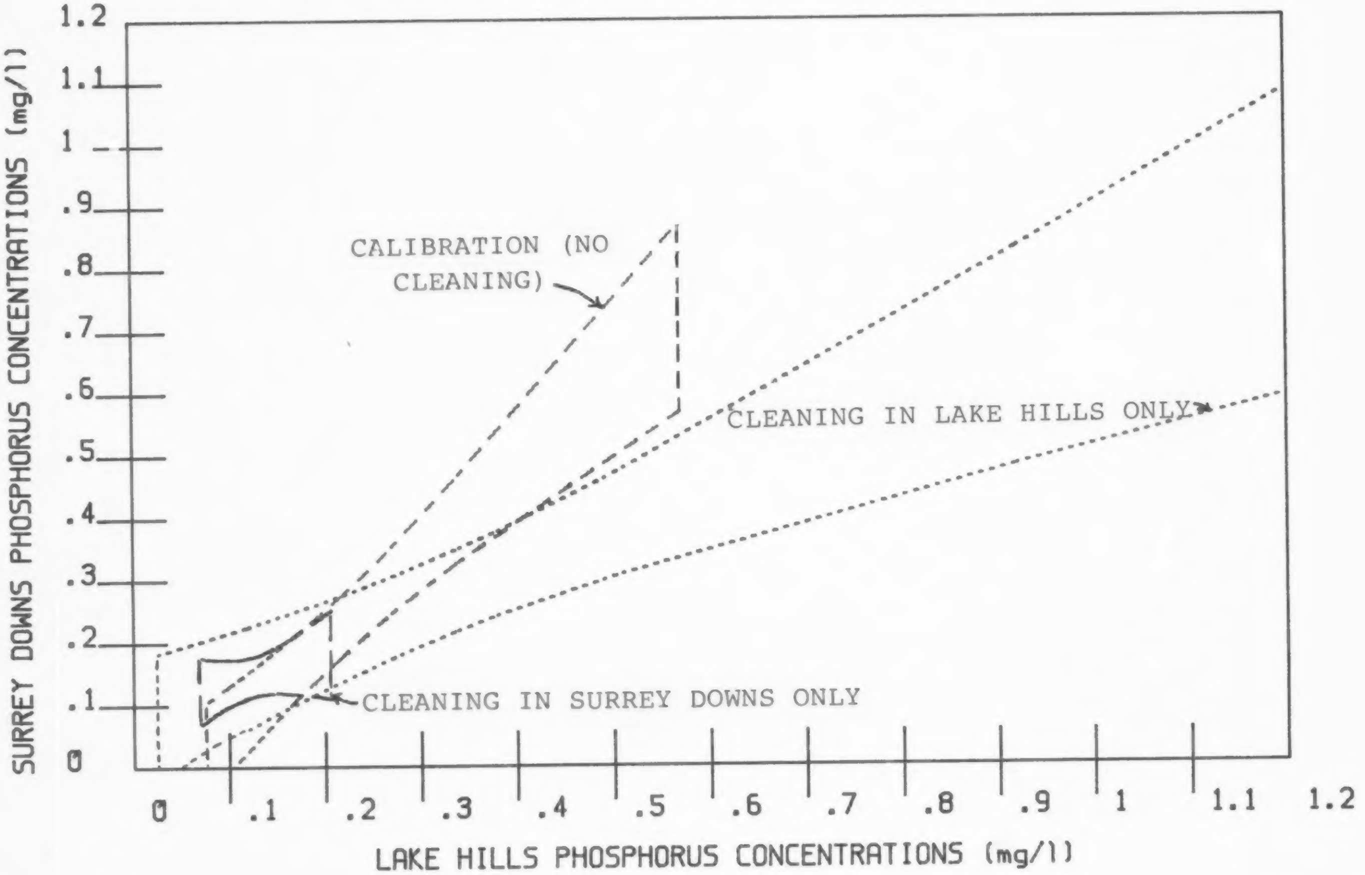


FIGURE 9-26

LEAD CONCENTRATION COMPARISIONS

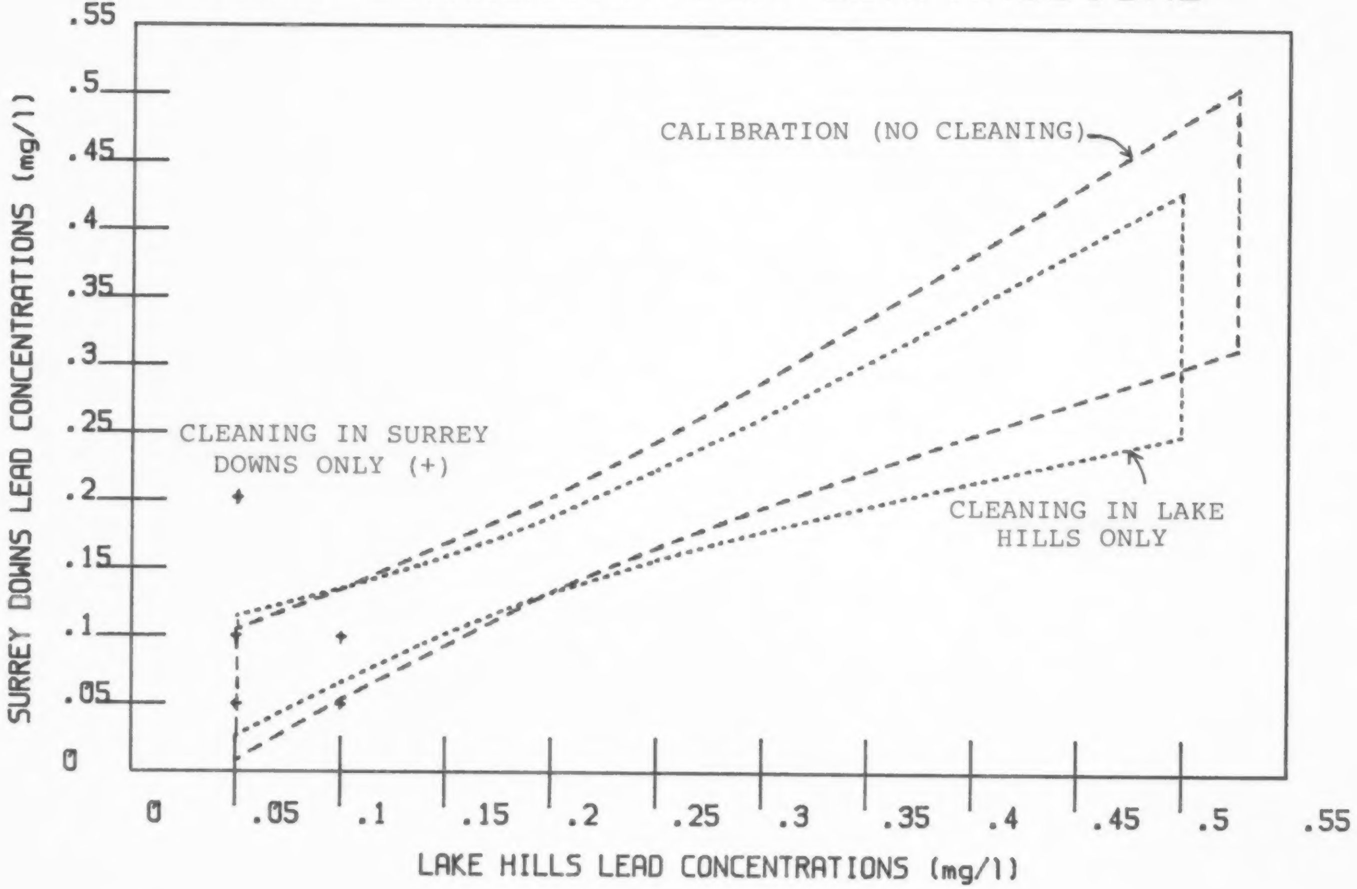


FIGURE 9-27

ZINC CONCENTRATION COMPARISIONS

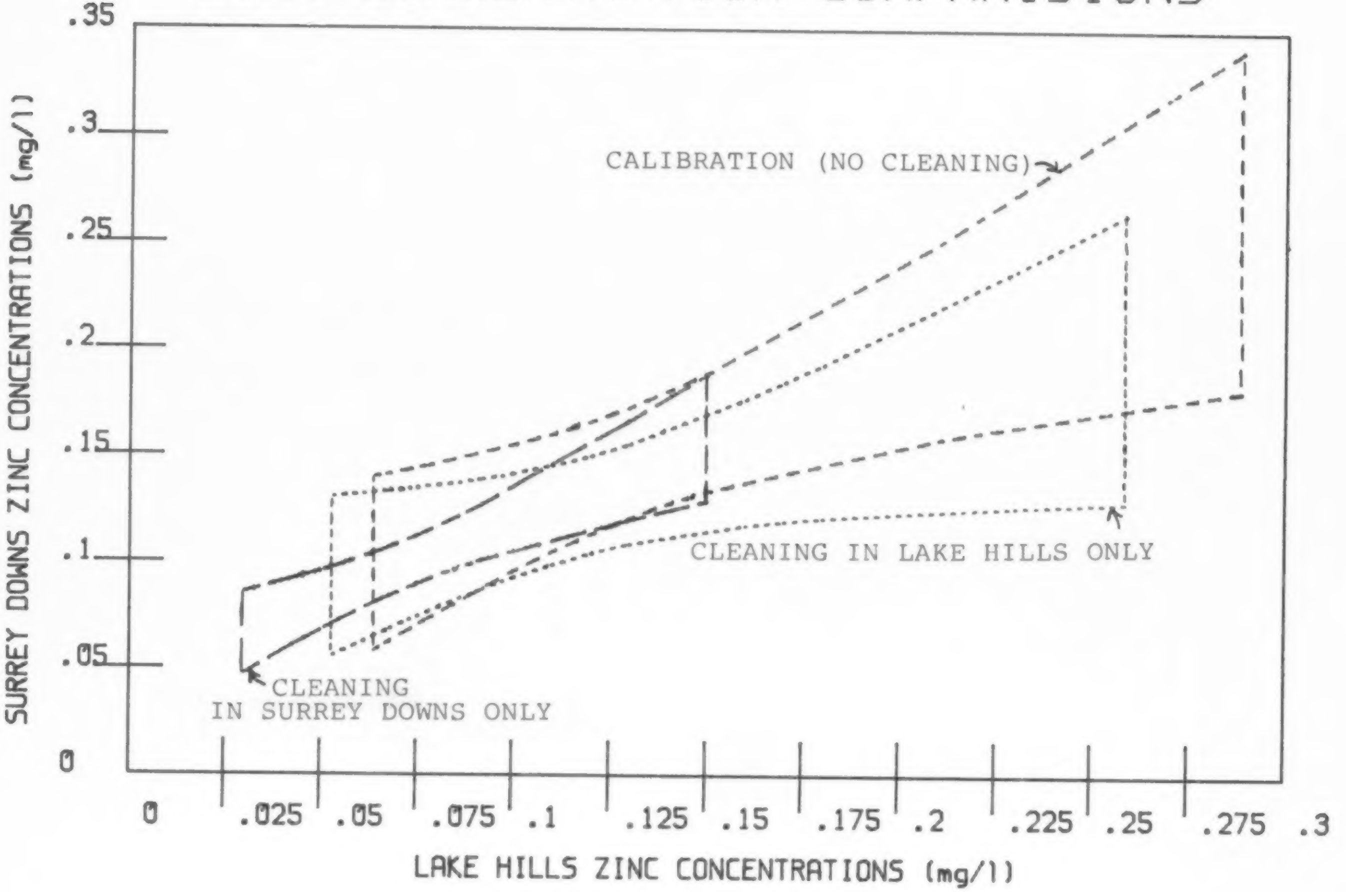


FIGURE 9-28

pH COMPARISIONS

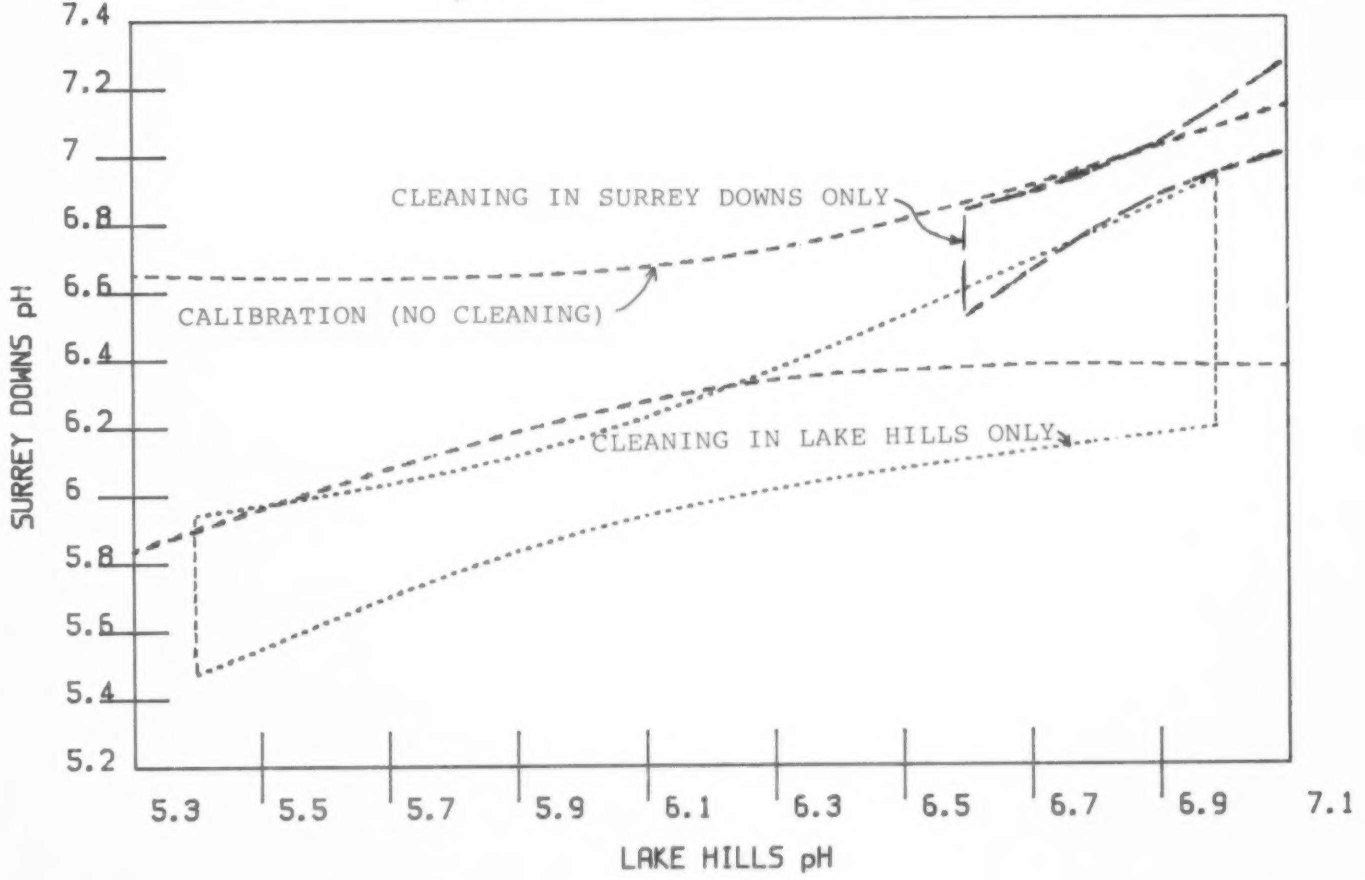


FIGURE 9-29

SPECIFIC CONDUCTANCE COMPARISIONS

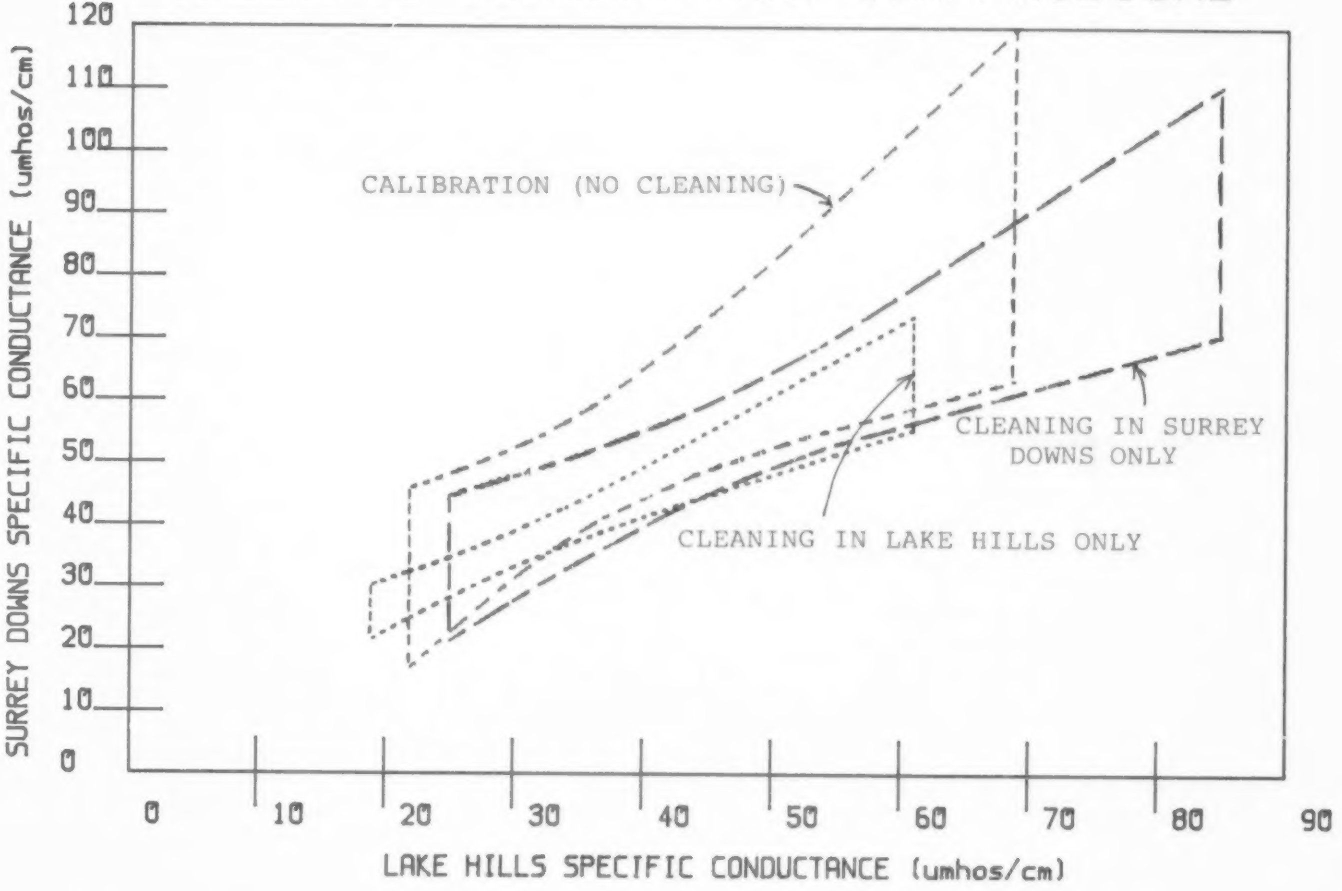
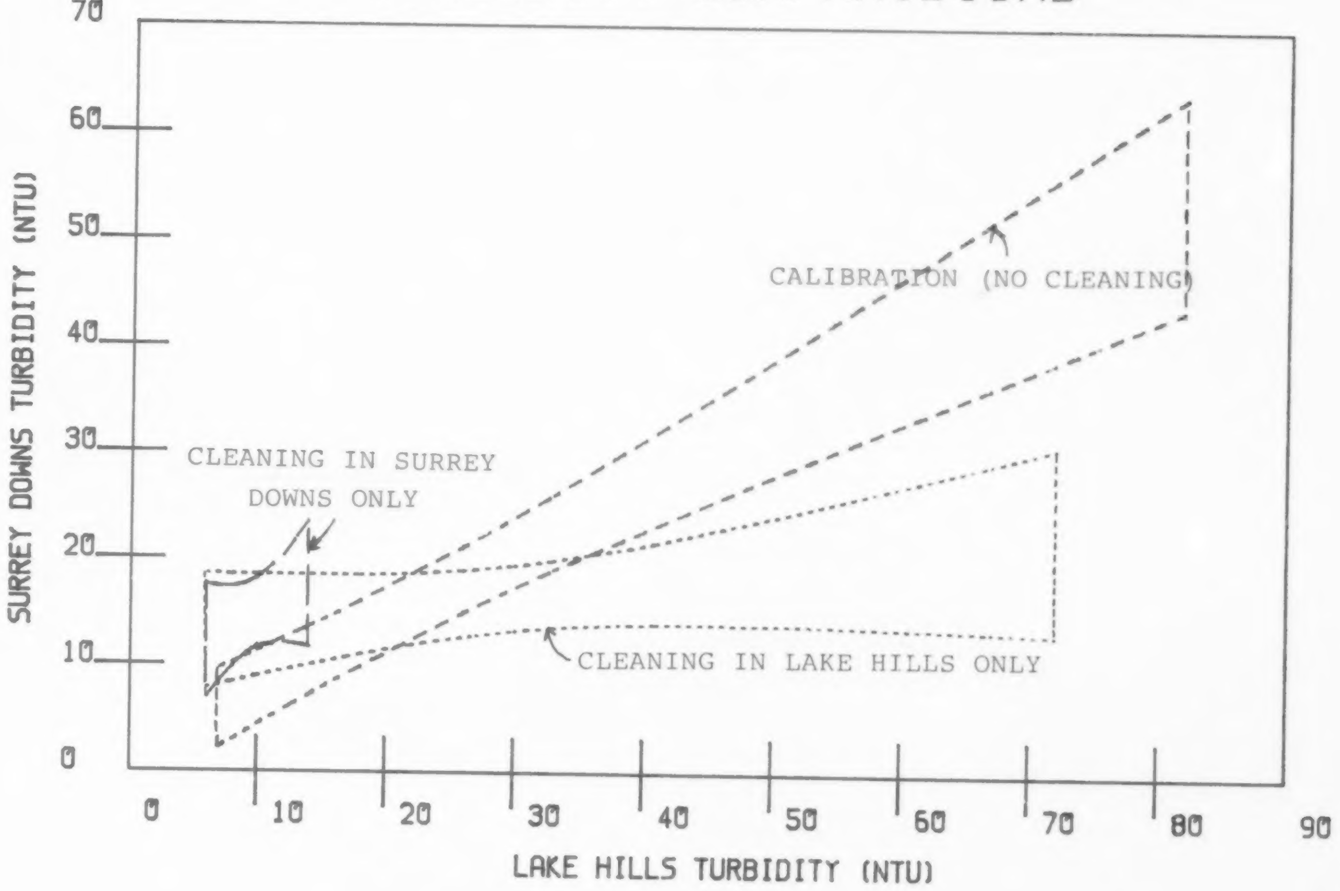


FIGURE 9-30

TURBIDITY COMPARISIONS



hundred microns. Therefore, street cleaning equipment can remove a fairly large fraction of the total street surface particulates, but they are not the particulates that can be removed by storms under the conditions observed in Bellevue. The removal of these larger particulates by street cleaning may actually increase storm washoff because of the loss of the armoring effects. These conclusions are very site specific and depend upon specific rainfall conditions (especially intensities, interevent times, and total rainfall quantities) and street surface conditions (especially texture and state of repair). In Castro Valley, California (Pitt and Shawley, 1981), the quite different rainfall and street surface conditions permitted street cleaning to improve runoff water quality by a maximum of about 25 to 40 percent for lead, total solids, and COD. Even under those more appropriate conditions for street cleaning, street cleaning had very little effect in controlling nutrient runoff concentrations and yields.

One of the main reasons Bellevue was selected as a test site by the Environmental Protection Agency, was because of its significantly different rain conditions when compared to other street cleaning test cities. The large number of rain events occurring evenly throughout the year (with each having small rain volumes and intensities) and the smooth street surfaces resulted in the frequent rains being capable of maintaining the street surface loadings at low levels, especially for the smaller particle sizes. Intensive street cleaning operations did significantly decrease the street surface loading conditions, but only for the larger particle sizes. The benefits of street cleaning in controlling nuisance and safety related street surface particulates are described in the following Section 10.

SECTION 10
STREET CLEANER PERFORMANCE

The design of an effective street cleaning program requires not only a determination of accumulation rates but also an assessment of the specific street cleaning equipment performance for the actual conditions encountered. Service goals which consider effects on water quality, air quality, public safety, esthetics, and public relations are the driving forces in establishing a street cleaning program. The major objective addressed in this section of the report is to determine the effectiveness of street cleaning equipment in reducing street particulate loadings. The previous Section 9 addressed the effects that reducing the street loads have on improving runoff water quality. It was seen that the measured runoff yields during periods of intensive street cleaning did not differ significantly from the runoff yields that were measured during periods of no street cleaning. However, Section 6 earlier had shown that street surface runoff contributes significantly to runoff yields for several pollutants. It was also shown in Section 9 that rain is most effective in removing the smallest street particulates. This section will discuss the effectiveness of street cleaning equipment in removing particulates of different sizes. It will be shown that conventional street cleaning equipment is most effective in removing the largest particle sizes: those that are not effectively removed by rains during storms. A series of special tests were also conducted and described using a modified regenerative air street cleaner that shows promise in effectively removing the smaller particle sizes. This section, therefore, describes the results of the full-scale street cleaning tests that were conducted during the runoff monitoring activities, the special tests using the modified street cleaner, special tests conducted to examine street cleaning effectiveness in other Bellevue areas, and tests conducted to examine the redistribution of street dirt during street cleaning. The effects of street cleaning on reducing runoff pollutants are also estimated, based on typical street dirt loading values observed for the different street cleaning programs and the washoff potentials for the different particle sizes. Finally, the Bellevue street cleaning program, equipment operating characteristics, and costs are presented.

Street cleaning performance depends on many conditions, including the character of the street surface (texture, condition, and type), street dirt characteristics (loadings and particle sizes), and other environmental factors. Street cleaning variables that most affect cleaning performance include the cleaning frequency and equipment adjustments. The most important measure of street cleaning effectiveness is "pounds per curb-mile" for a specific program condition. This removal value, in conjunction with the unit curb-mile costs, allows the cost for removing a pound of pollutant for a

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specific street cleaning program to be calculated. The "percent of the before loading removed" is commonly used, but can be misleading. The percentage removed is not a measure of the magnitude of material removed. A street cleaning program may have a very low percentage removal, but a large amount of material may be removed if the initial loading is large. The percentage removal values can be useful when normalized values are needed, such as when comparing two different programs under similar loading conditions.

STREET CLEANING TEST SCHEDULE

An important aspect of the project was to conduct street cleaning activities in monitored watersheds. The runoff from many storms was analyzed for a variety of constituents during periods of intensive street cleaning (three passes per week) and during periods of no street cleaning. This runoff data was presented in Section 9. The two test watersheds (Surrey Downs and Lake Hills) were cleaned during alternate periods. This cleaning schedule allowed periods of different climatic conditions in both watersheds to be affected by street cleaning. Several periods of no street cleaning also occurred simultaneously in both basins to calibrate their runoff responses. Table 10-1 shows the street cleaning schedule for these full-scale tests in the monitored watersheds. The first street cleaning tests were conducted in the Surrey Downs basin, starting on April 2, 1980. These streets were cleaned about three times a week (except when rains forced the cancellation of the street cleaning) until July 9, 1980. No cleaning occurred in either basin until September 15, when street cleaning started in the Lake Hills basin, again at three times per week. Street cleaning in Lake Hills lasted until July 1, 1981, except for a period from the end of November to the beginning of January during a period of consistent rains. During this one year period, no street cleaning occurred in Surrey Downs. Cleaning again started in Surrey Downs on September 29, 1981 (after a period of no cleaning in either basin), and ended on December 23, 1981. A total of 44 street cleaning tests were conducted in Surrey Downs, and 77 tests were conducted in Lake Hills for a total of 121 full-scale tests during this 20-month period. Three calibration periods also occurred, during August of both years and during December of 1980. This schedule therefore included intensive street cleaning and calibration periods having no cleaning in both basins during both the wet and dry seasons. The climatic conditions varied somewhat during both years, however, as described in Section 4. The special modified street cleaner tests were conducted during the summer of 1982.

Each street cleaning test included measurements of the street particulate loading conditions before and after each street cleaning pass. The sampling procedures used were identical to those used when collecting accumulation samples (street loading measurements in the basin not being cleaned). These sampling procedures are described in Appendix E. Therefore, complete loading histories were obtained for each basin during the period of the project. These samples were collected from six times a week (in basins with three street cleanings per week) to once a week (for basins not being cleaned). Section 7 described the street dirt accumulation characteristics during the project period. Complete precipitation histories were also

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Table 10-1. FULL-SCALE STREET CLEANING TEST SCHEDULE

		Cleaning dates for:(1)	
Season	Month	Surrey Downs	Lake Hills
dry	April, 1980	2,7,11,16,18,21,23,25,30	none
dry	May	5,7,9,12,14,16,19,30	none
dry	June	4,11,13,16,18,20,30	none
dry	July	2,7,9	none
dry	August	none	none
dry	September	none	15,17,22,24,26,29
wet	October	none	1,3,6,10,13,17,22,27,29
wet	November	none	5,10,12,17,19,24,26
wet	December	none	15
wet	January, 1981	none	5,9,12,19,21,30
wet	February	none	2,4,13,17,20,23
dry	March	none	2,4,6,9,11,13,16,20,24,25,27
dry	April	none	2,3,6,8,10,13,15,17,21,23,24,29
dry	May	none	1,4,6,8,12,13,15,21,22
dry	June	none	1,5,11,17,23,24,26,29
dry	July	none	1
dry	August	none	none
dry	September	29,30	none
wet	October	2,12,16,20,21	none
wet	November	2,5,16,24	none
wet	December	7,11,14,16,21,23	none

(1) approximately three times a week street cleaning, except for holidays and days of rain

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collected during the project.

Figure 10-1 is an example of this data plotted for a 65-day period for Surrey Downs from August 24 to October 28, 1981. At the beginning of this period, Surrey Downs was not being cleaned. Street cleaning started on September 29th. The street cleaning days are shown on the plot, along with the rain periods. The street loadings ranged from about 300 to 500 lbs/curb-mile (85 to 140 g/curb-meter) (with an extreme value of about 900 lbs/curb-mile, or 260 g/curb-meter) during the period of no street cleaning. The loadings reduced to values from about 150 to 250 lbs/curb-mile (40 to 70 g/curb-meter) shortly after the start of street cleaning. Median particle sizes are shown on this figure and are also seen to decrease with the start of cleaning. The significant effects that rains had on the street dirt loadings and particle sizes is evident. The rain periods shown all reduced the street loadings appreciably (except for the largest rain observed during the study which occurred during this period) and increased the median particle size values. This indicates that the rains washed off the fine material more efficiently than the larger material (as discussed in Section 9). The largest rain had little effect on the net loading change, probably because of substantial erosion material carried to the street during this major storm.

This figure indicates that the street loadings responded rapidly to street cleaning. The loading data collected can therefore be considered responsive to the street cleaning conditions, with little lag time between changes in the street cleaning program. Changes from periods of street cleaning to no street cleaning were not as rapid. However, the street cleaning accumulation rates, as described in Section 7, were shown to be largely controlled by the frequent rains during periods of no street cleaning. Therefore, loading values are expected to be stabilized after about three street cleanings or rains.

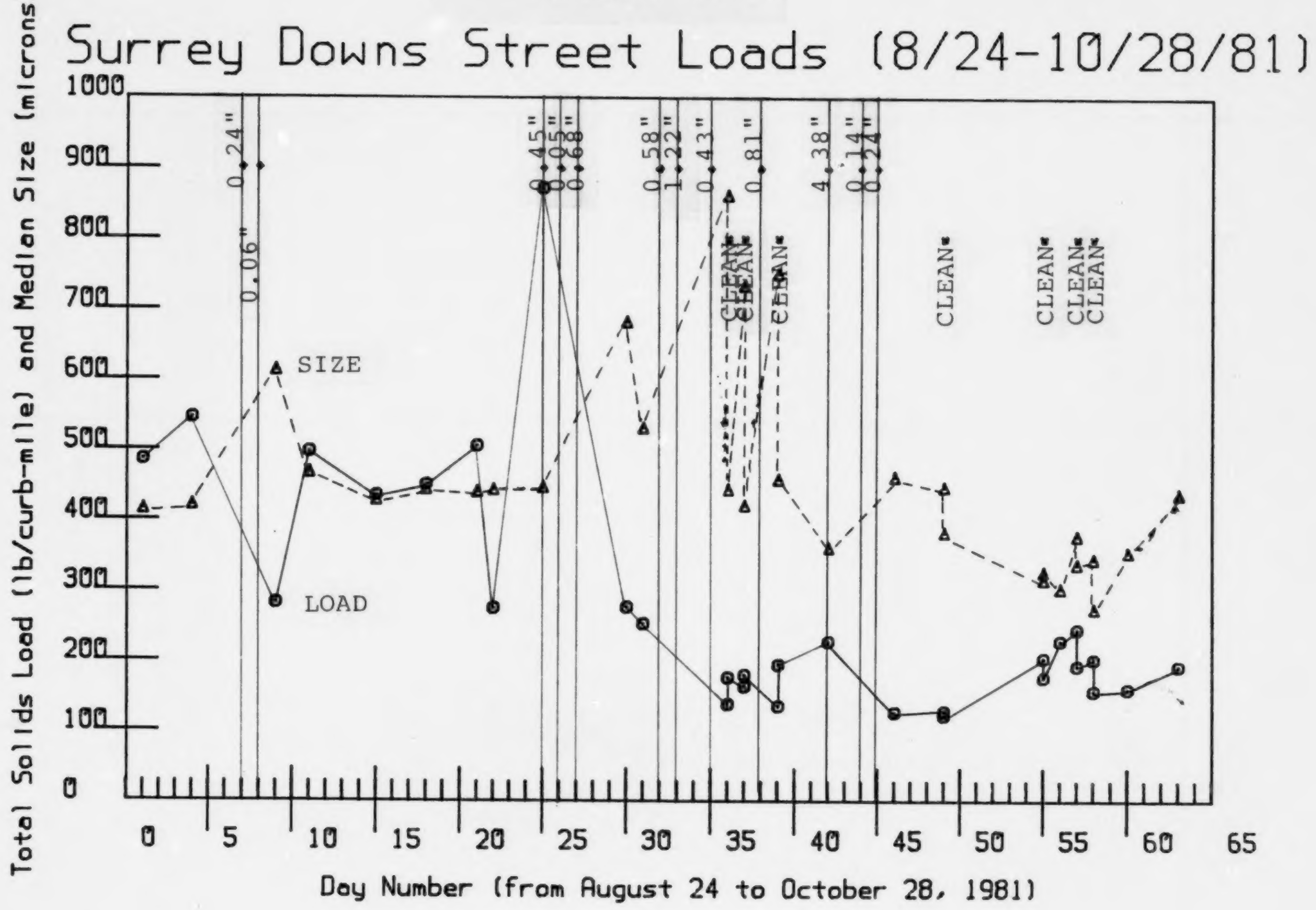
PERFORMANCE TESTS

Several types of street cleaning performance tests were conducted during this project. The large scale tests described above required the most effort and resulted in the most data. Selected tests were also conducted at a variety of other land-use sites in Bellevue to check the transferability of the full-scale test results. Two tests were also conducted to measure the redistribution of street dirt across the road caused by street cleaning. An intensive series of tests were also conducted to examine the effectiveness of a modified regenerative air street cleaner. These test results are presented and discussed in the following subsections.

Full-Scale Tests

The street loading data presented in Appendix B contains the total solids initial and residual loading values and median particle sizes for the full-scale tests. Complete data lists for all particle sizes are too bulky to present in this report, but are contained in the STORET data base operated by

FIGURE 10-1



Surrey Downs Street Loads (8/24-10/28/81)

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EPA. The Lake Hills STORET station number is 208BELL0582 and the station number for Surrey Downs is 208BELL0583. These are special NURP STORET files and only contain street dirt loading information. The STORET data can be used in conjunction with the data presented in Appendix B for a complete description of the street loading history at the two main Bellevue street cleaning test sites.

The most useful way to present street cleaning effectiveness data is on a graph relating residual loadings to initial loadings. Such figures are shown as Figures 10-2 and 10-3 for total solids and median particle size. Appendix C contains figures for particle sizes ranging from greater than 6370 microns (about 1/4 inch) to less than 63 microns (Figures C-1 to C-8). The relatively large number of street cleaning tests (121) enabled the effectiveness relationships to be described in detail. It was found that both Lake Hills and Surrey Downs data could be combined for statistical analyses. The Surrey Downs data represented loadings over a wider range of initial loading conditions (from about 80 to 700 lbs/curb-mile, or 23 to 200 g/curb-meter) than the Lake Hills data (from about 90 to 390 lbs/curb-mile, or 25 to 110 g/curb-meter). The lower Surrey Downs data is shown to overlay the Lake Hills data on these figures.

In earlier studies (Pitt, 1979, and Pitt and Shawley, 1981), the fewer data available indicated "straight-line" relationships between the initial and residual loads, with "negative" removals associated with the lowest loadings. The greater number of data available during this project, however, has refined this model. The effectiveness figures presented in this section and in Appendix C indicate no effective removal by street cleaning until a minimum initial loading value is obtained. Above this minimum value, street cleaning can be quite effective. The scattered data before this minimum value is obtained include many cases where the residual loadings were greater than the initial loadings. These negative removal values may be associated with street wear (as was noted in Pitt's 1979 San Jose study, especially for multiple street cleaning passes every day on streets in poor condition). This data scatter may also be due to sampling error, as the street dirt sampling procedures were designed to result in errors of about 25 percent.

The minimum value before street cleaning is effective varies for each particle size, street surface texture and condition, and equipment operating characteristic. Table 10-2 summarizes these minimum values for the Surrey Downs, Lake Hills, and S.E. 30th study areas. Also shown are the maximum values under which the loadings are usually maintained for these street cleaning operations. It can be seen how referring to percent removals can be misleading. For the same area, cleaning frequency, and equipment type, the percent removal varies from nothing until the minimum value is obtained, then slowly increases to values approaching about 30 percent for total solids. In some cases, the maximum percent removal values may be as large as 80 percent. If the street loading values must be maintained below a certain maximum loading value, then each cleaning event required would have very low percent removal values.

These figures show how ineffective typical mechanical street cleaning can be for removing small particle sizes. For the conditions observed, there

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FIGURE 10-2

Street Cleaner Performance: Total Solids

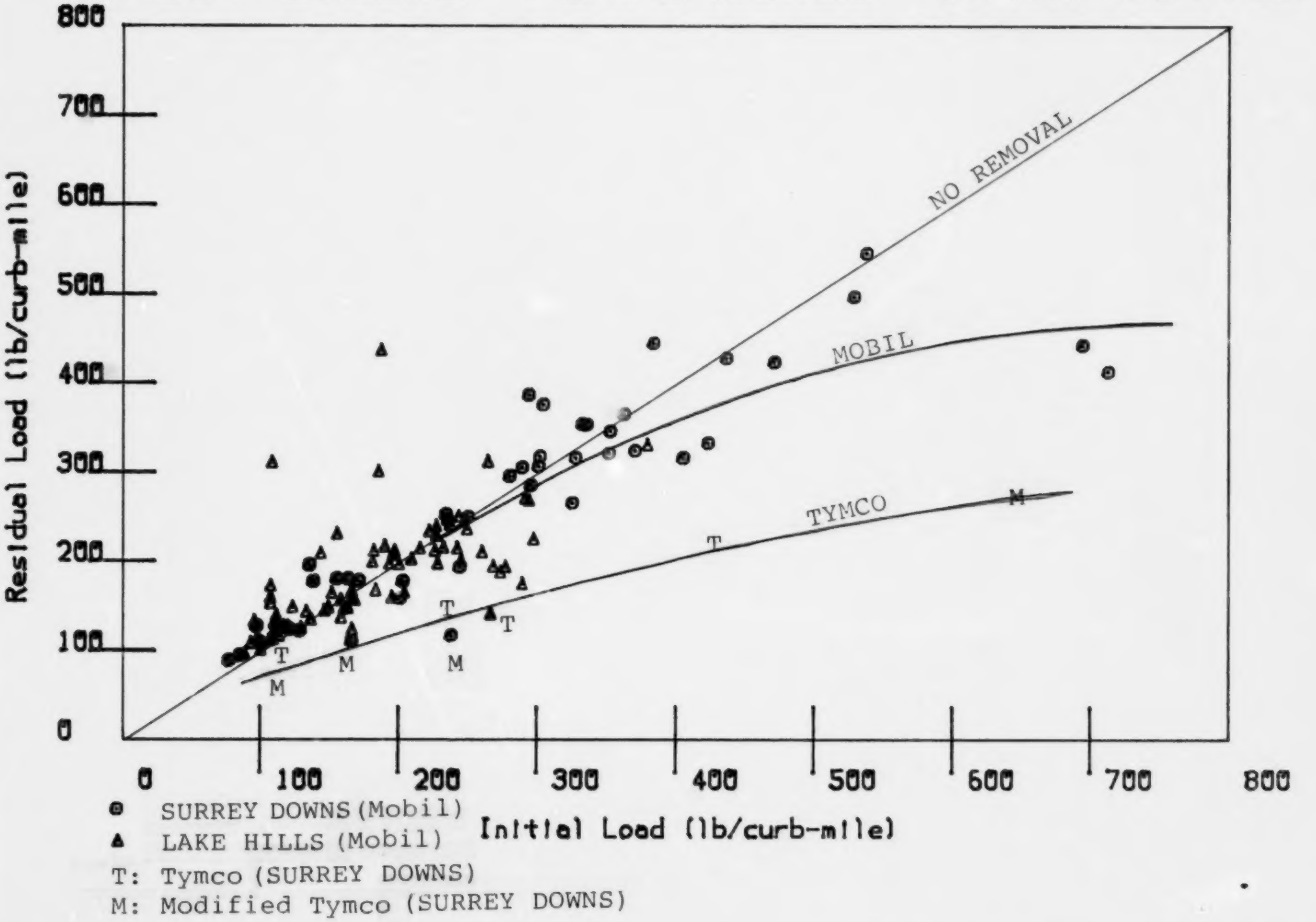

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FIGURE 10-3

Street Cleaner Performance: Particle Size

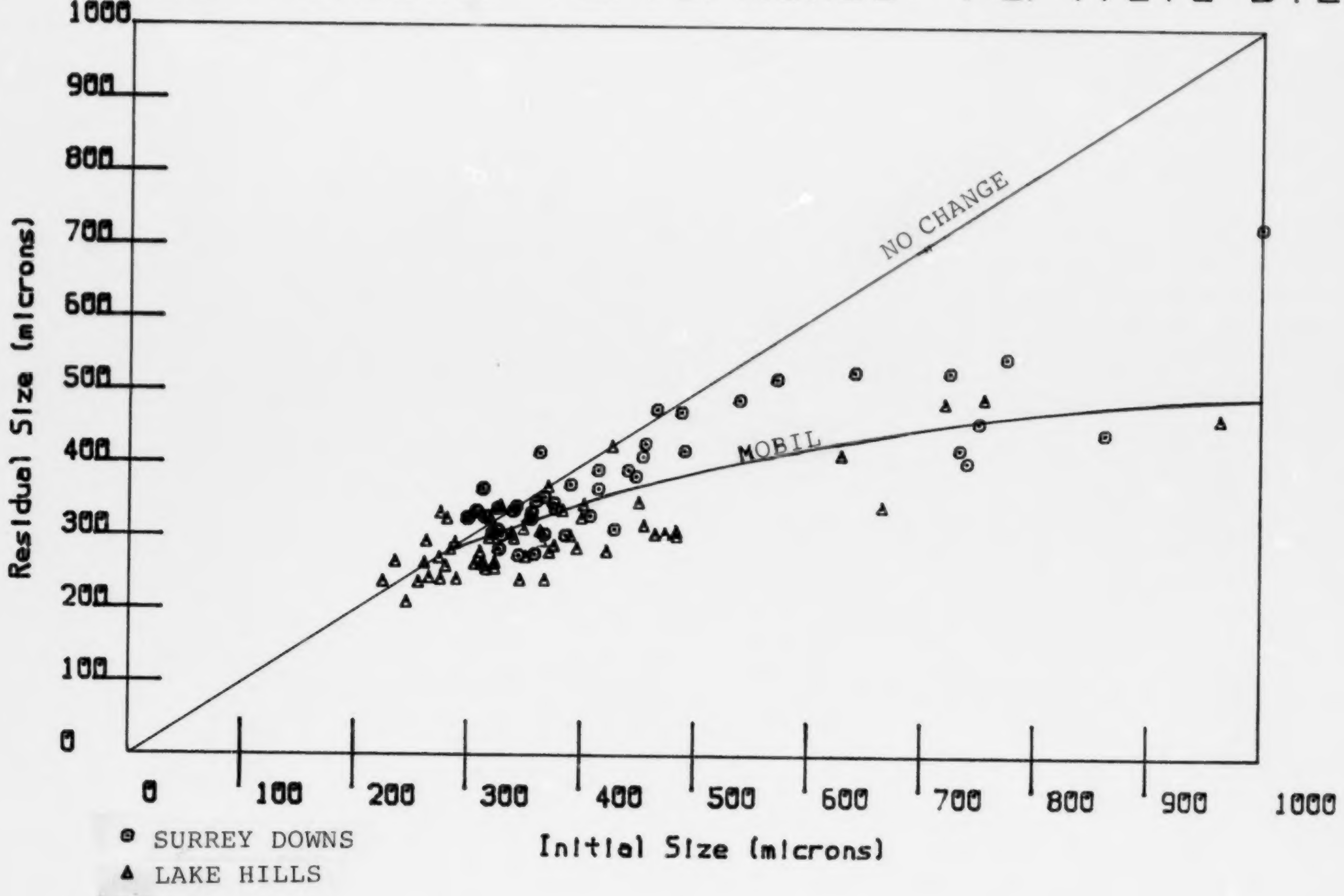

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TABLE 10-2. TYPICAL MINIMUM LOADS FOR EFFECTIVE CLEANING AND MAXIMUM LOADS AFTER CLEANING (LBS/CURB-MILE).

Size (microns) SD and LH:	MOBIL Minimum initial load before removal	MOBIL Maximum expected residual load	TYMCO Minimum load before removal	TYMCO Maximum expected residual load
TS	350	450	100	300
>6350	5	15	--	3
2000 - 6350	15	30	3	10
1000 - 2000	25	50	5	20
500 - 1000	60	80 +	10	50
250 - 500	70	90 +	10	60
125 - 250	70	90 +	10	50
63 - 125	--	--	10	30
<63	--	--	20	40
<37	--	--	5	--
< 2	--	--	0.1	--
SE-30th				
TS	insufficient data		200	500
>6350			5	10
2000 - 6350			20	40
1000 - 2000			50	--
500 - 1000			50	--
250 - 500			50	--
125 - 250			25	200
63 - 125			15	--
<63			25	--
<37			20	60
<2			0.2	--

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was no effective removal of particles smaller than about 125 microns. Very substantial removals were measured for large particles, however. Figure 10-3 indicates the dramatic decrease in median particle size as the street cleaners preferentially removed the larger particles.

Street Cleaning Effectiveness at Other Bellevue Locations

During the second year of the project (April and May, 1981), street cleaning tests were conducted at eight other land-use sites in Bellevue. The land-uses included downtown Bellevue, shopping centers, high density residential areas, low density residential areas, and industrial areas. Table C-1 shows these data for all particle sizes. Unfortunately, only one or two tests were conducted at each site, so individual analyses of the land-uses were not possible. Figure 10-4 is a plot of the initial versus residual values for all of this data combined. These data appear to fall on the total solids curve presented earlier (as Figure 10-2) for the large-scale tests. The S.E. 30th and 2nd Avenue industrial sites had much greater initial loads than elsewhere, but the street cleaners were quite effective in substantially reducing the loadings. The minimum initial loadings before effective removal was about 300 to 400 lbs/curb-mile (85 tp 110 g/curb-meter), quite similar to the values shown in Table 10-2 for the Surrey Downs and Lake Hills sites.

Figure 10-5 shows the strong relationship between percent removals and initial loadings. The clean streets had very low removal percentages, while the very dirty streets had high removal percentages, even though the Figure 10-4 data seem to fit the general model. Such different percentage removal values imply different removal models.

Redistribution of Street Dirt Across the Street During Street Cleaning

Two special tests were conducted in and near the Surrey Downs test area to examine the loading gradient across the streets, before and after street cleaning. This data, for all particle sizes, is shown in Appendix Table C-2. Figures 10-6 and 10-7 show the total solids unit area loading data plotted. The unit area loadings in the ten inches (254 mm) next to the curb were reduced substantially in both tests. The other street segments experienced variable loading changes. These changes indicate substantial movement of the near curb dust and dirt away from the curb by the gutter brooms. The main pick-up brooms were not able to remove all of this moved material. These results are similar to tests conducted on a variety of different street cleaners in the past (Sartor and Boyd, 1972, and Pitt, 1979).

Effectiveness of Modified Street Cleaners

A series of special tests were conducted during September and October, 1982, to compare the effectiveness of a modified street cleaner to standard street cleaners. Air Pollution Technology, Inc. (APT), of San Diego, California, designed and installed many modifications to a standard regenerative air street cleaner while under contract to EPA (William

FIGURE 10-4

Cleaning Productivity for Misc. Sites

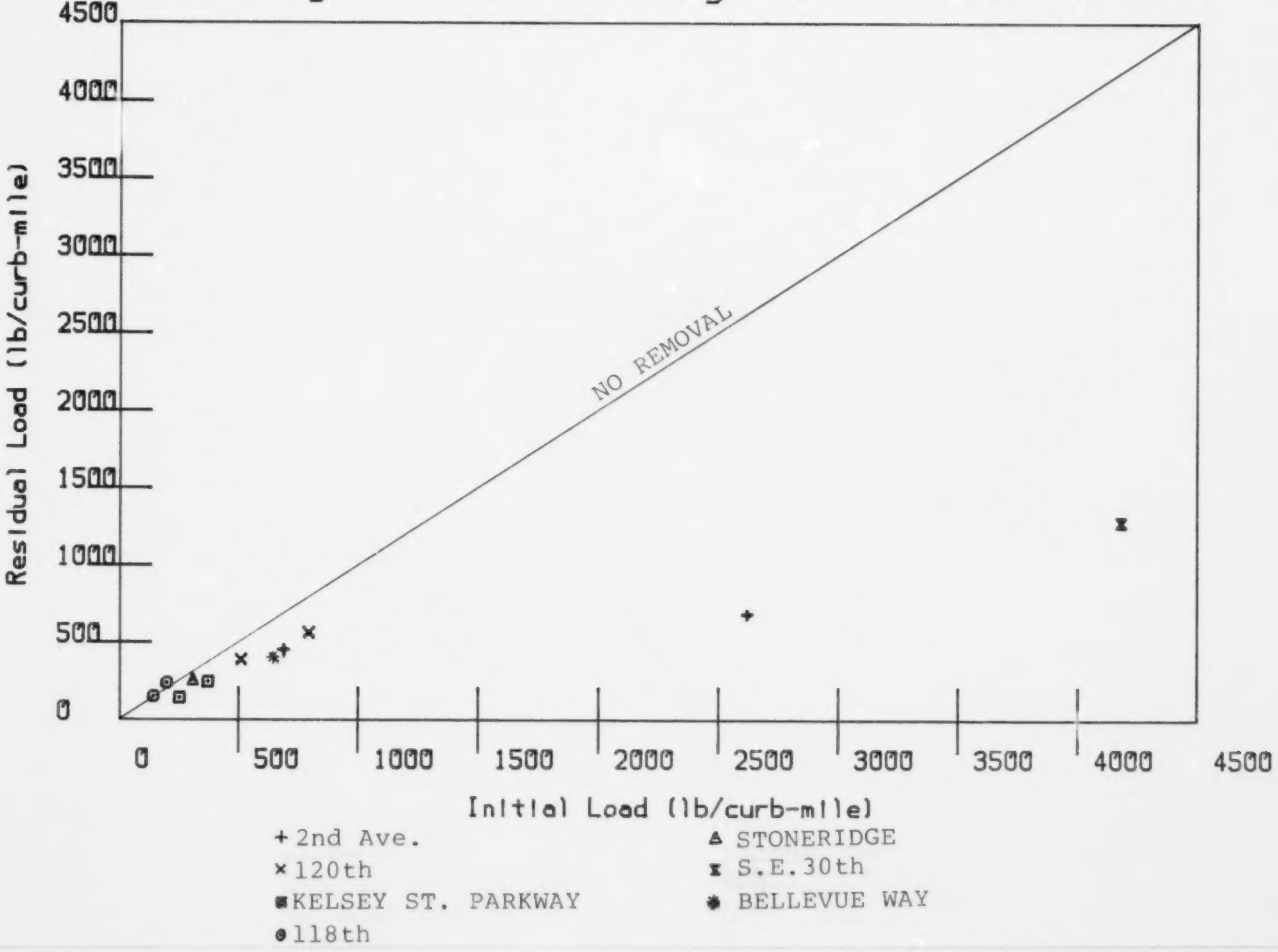


FIGURE 10-5

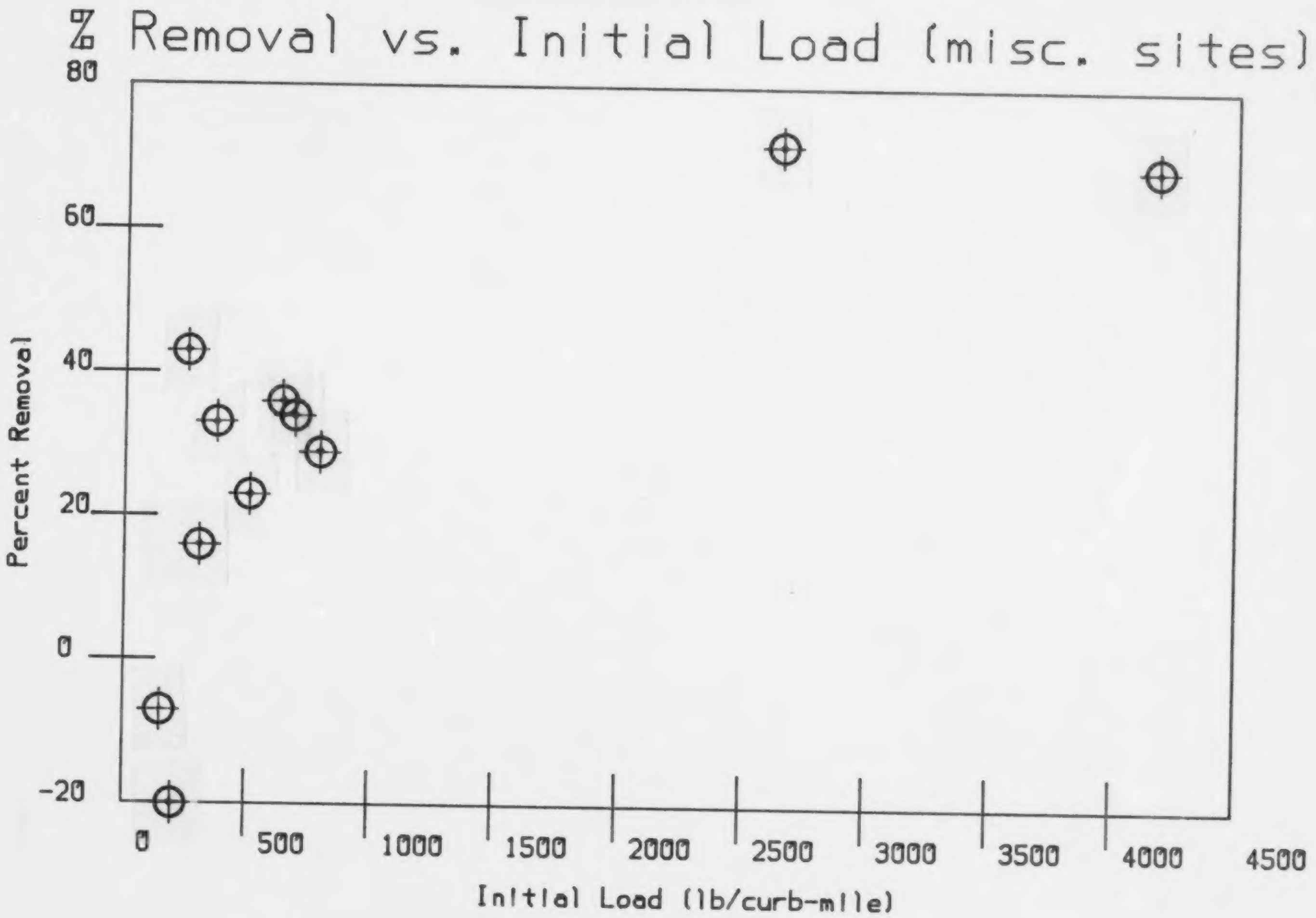
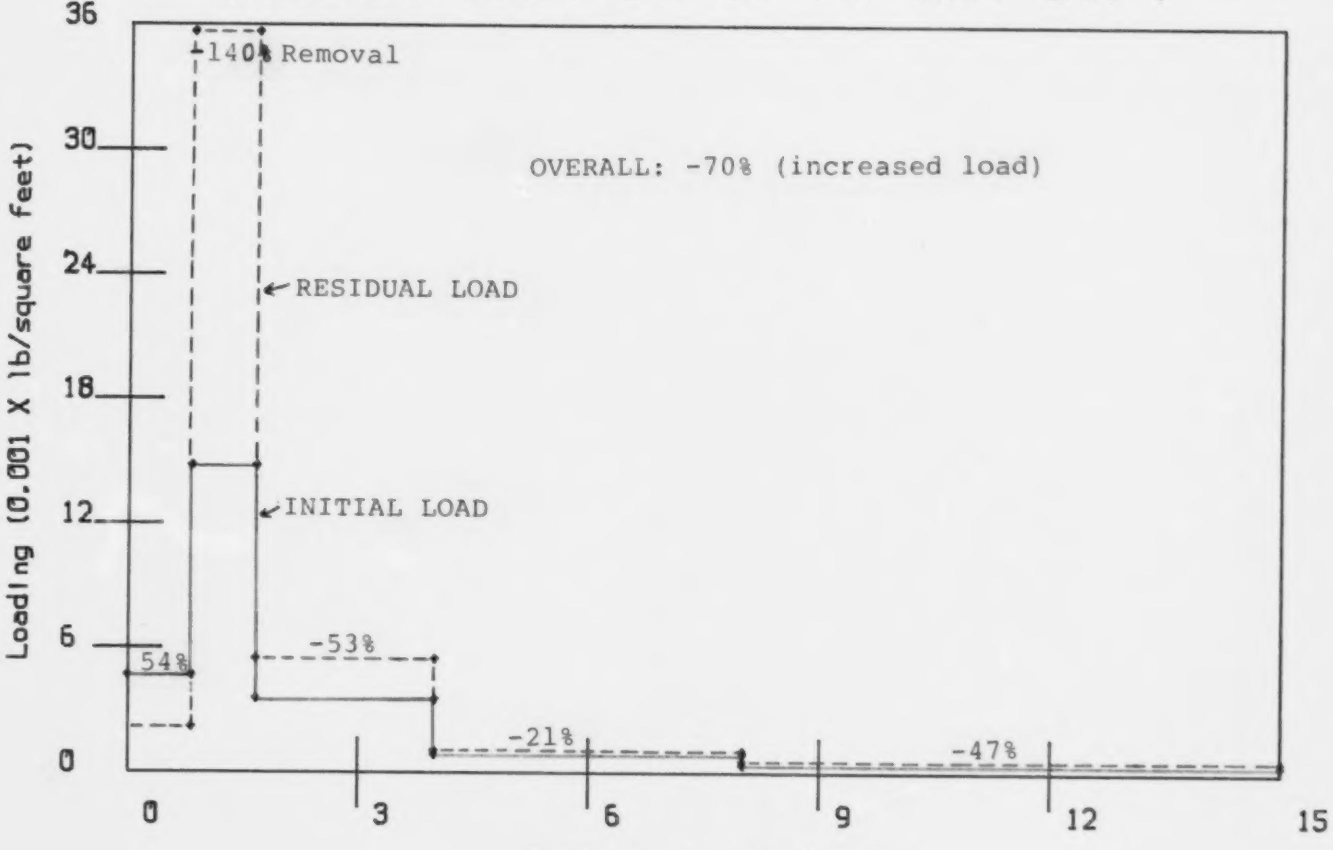

% Removal vs. Initial Load (misc. sites)
Percent Removal
80
60
40
20
0
-20
0
500
1000
1500
2000
2500
3000
3500
4000
4500
Initial Load (lb/curb-mile)

FIGURE 10-6

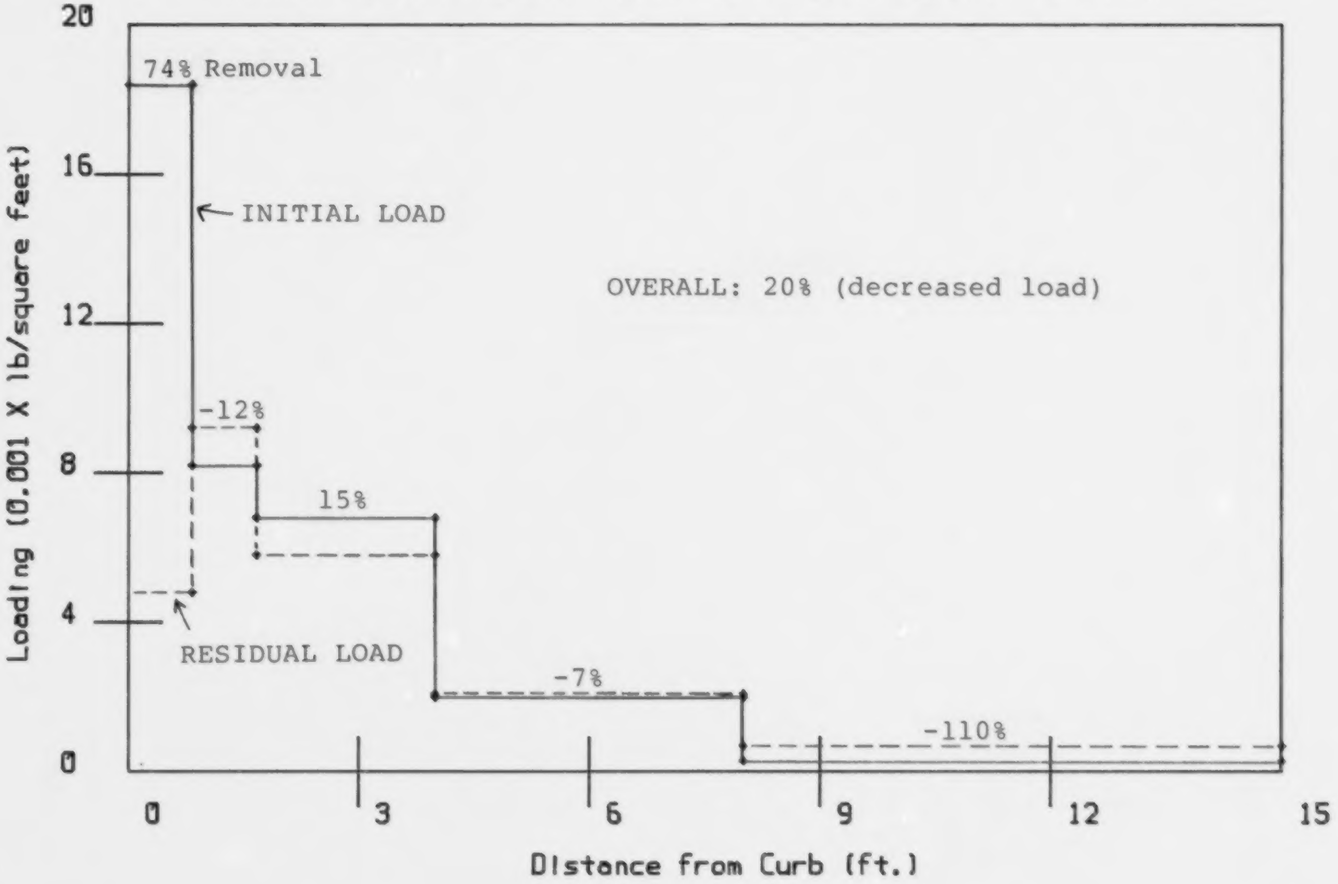
Redistribution of Street Dirt



115 110th Ave. S.E. Site

FIGURE 10-7

Redistribution of Street Dirt



405 110th Ave. S.E. Site

Kuykendal, Project Officer, Research Triangle Park, North Carolina). The purpose of the modifications was to reduce respirable fugitive dust emissions during street cleaning activities. The modifications included partial hoods around the gutter brooms, a pressure controller to better regulate the air flows, and a venturi scrubber with a settling chamber in the street cleaner hopper. The water spray bar was also disconnected. These modifications were described in the first phase report prepared by APT for EPA (EPA Contract No. 68-02-3148). APT was awarded a second contract phase to refine the modifications and conduct extensive field trials of street cleaner effectiveness. An arrangement was made to test the modified street cleaner in Bellevue, in order to take advantage of the preexisting information relating street cleaning and runoff water quality. The modified street cleaner was compared both to a standard broom street cleaner that was used during the previous Bellevue tests, and to itself, with the modifications disconnected. The purpose of these special Bellevue tests was to estimate any effect the modifications may have on improving urban runoff water quality. APT has conducted additional tests in San Diego to study air quality effects during street cleaning.

Surrey Downs and S.E. 30th Avenue (an industrial street that was previously determined to be one of the dirtiest streets in Bellevue) were used for most of the tests. Each area was divided into six subsampling sections. The three equipment types were rotated through these sub-areas at various cleaning frequencies. This allowed the street loadings to vary over a relatively wide range of values for each equipment type. Table C-3 shows the results of these tests for all particle sizes. Four or five cleaning tests were conducted for each equipment type. In addition, several test measurements were made separating the cleaning width loadings from the full street width loadings. Figures 10-8 and 10-9 are the usual initial load versus residual load effectiveness diagrams for Surrey Downs and S.E. 30th, respectively. Appendix Figures C-9 through C-30 show the effectiveness relationships for each particle size. These figures represent full street width loadings, and are therefore comparable with the earlier full-scale test figures. The broom cleaner results are very similar to the previously reported results, but the regenerative air cleaner (modified and not modified) shows substantially better performance. This is especially true when the finer particle sizes are considered. The broom cleaner shows very little removal (the loadings are too low) for particle sizes less than 1000 microns. The regenerative air cleaners appear much more suited for these lower loadings for the smaller particle sizes. The data for the smallest particle sizes (less than 125 microns) are inconsistent, implying little consistent removal effectiveness by any of the street cleaners. Similar results are shown for both the study sites. The smallest particle size (less than two microns) showed better removal effectivenesses for the regenerative air street cleaners than for the broom street cleaner, in most cases.

To differentiate the modified and standard regenerative air street cleaners, data are presented in Figures 10-10 and 10-11 for total solids loadings in the cleaning width only. The modified street cleaner is seen to have almost a constant residual loading value in the cleaning width after cleaning, irrespective of the initial loading. This indicates a very important advantage in cleaning effectiveness for the modified regenerative

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FIGURE 10-8

Surrey Downs Total Solids

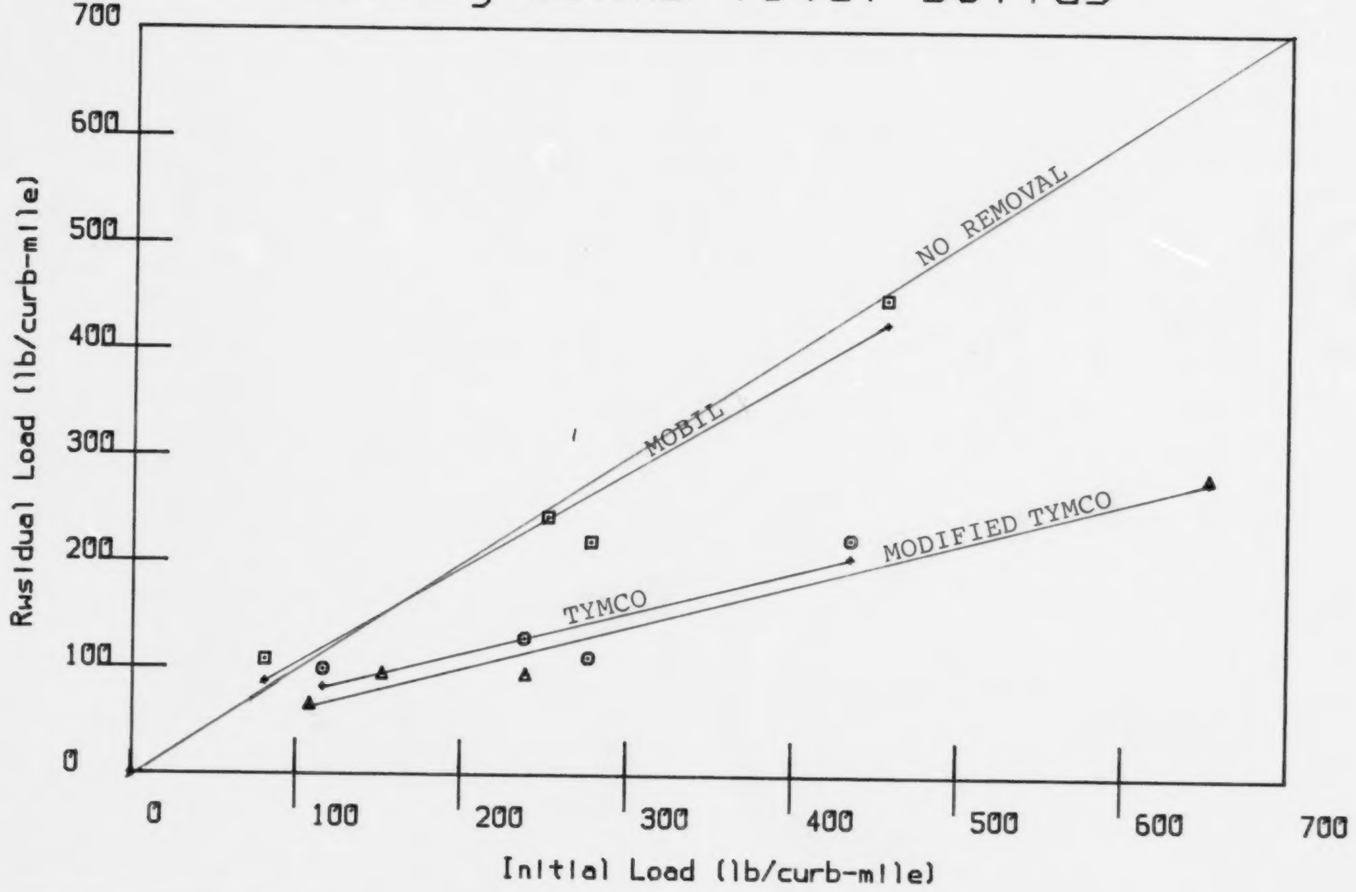

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FIGURE 10-9

S.E. 30th Total Solids

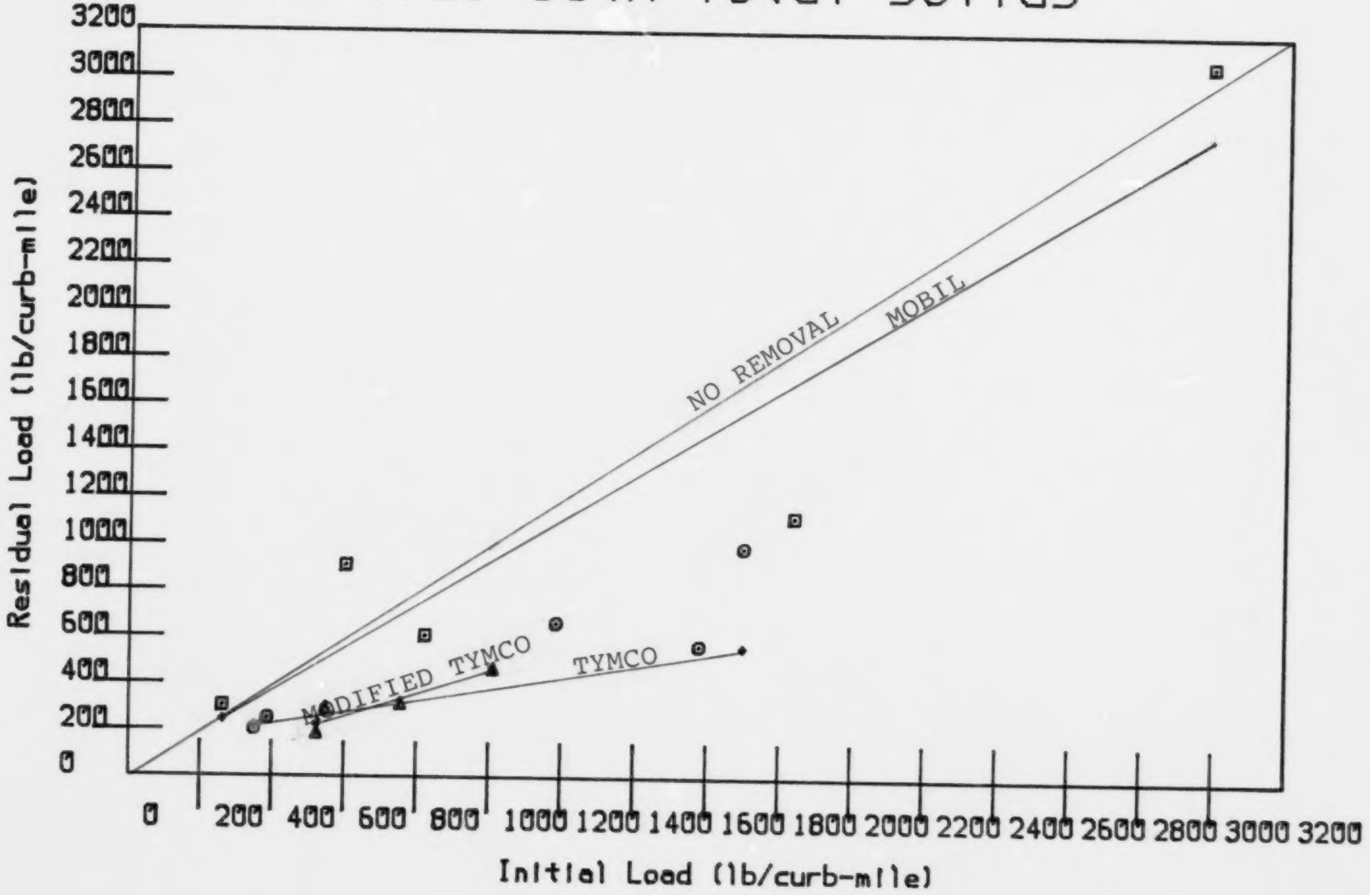

FIGURE 10-10

Surrey Downs Cleaning Width

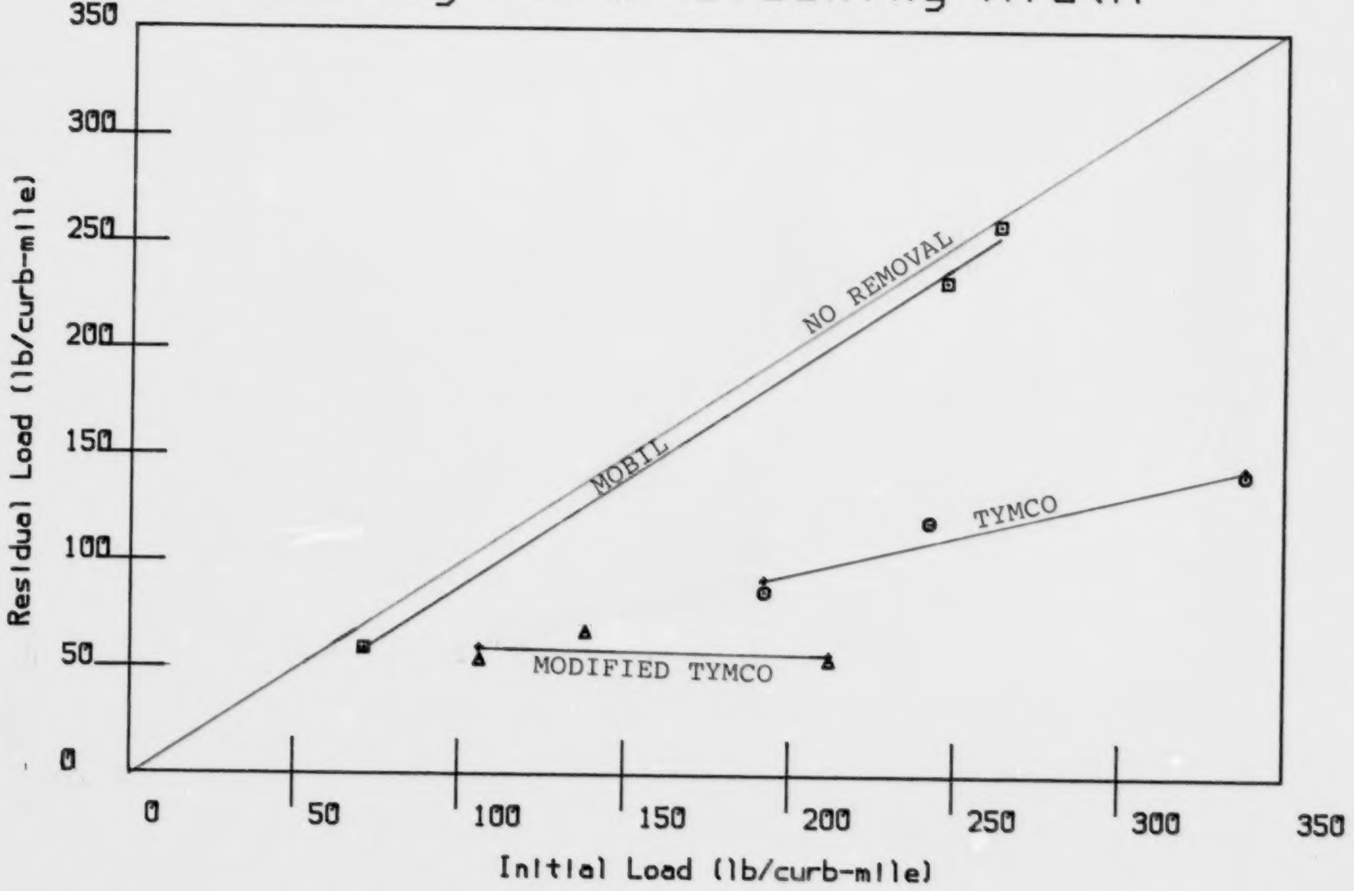

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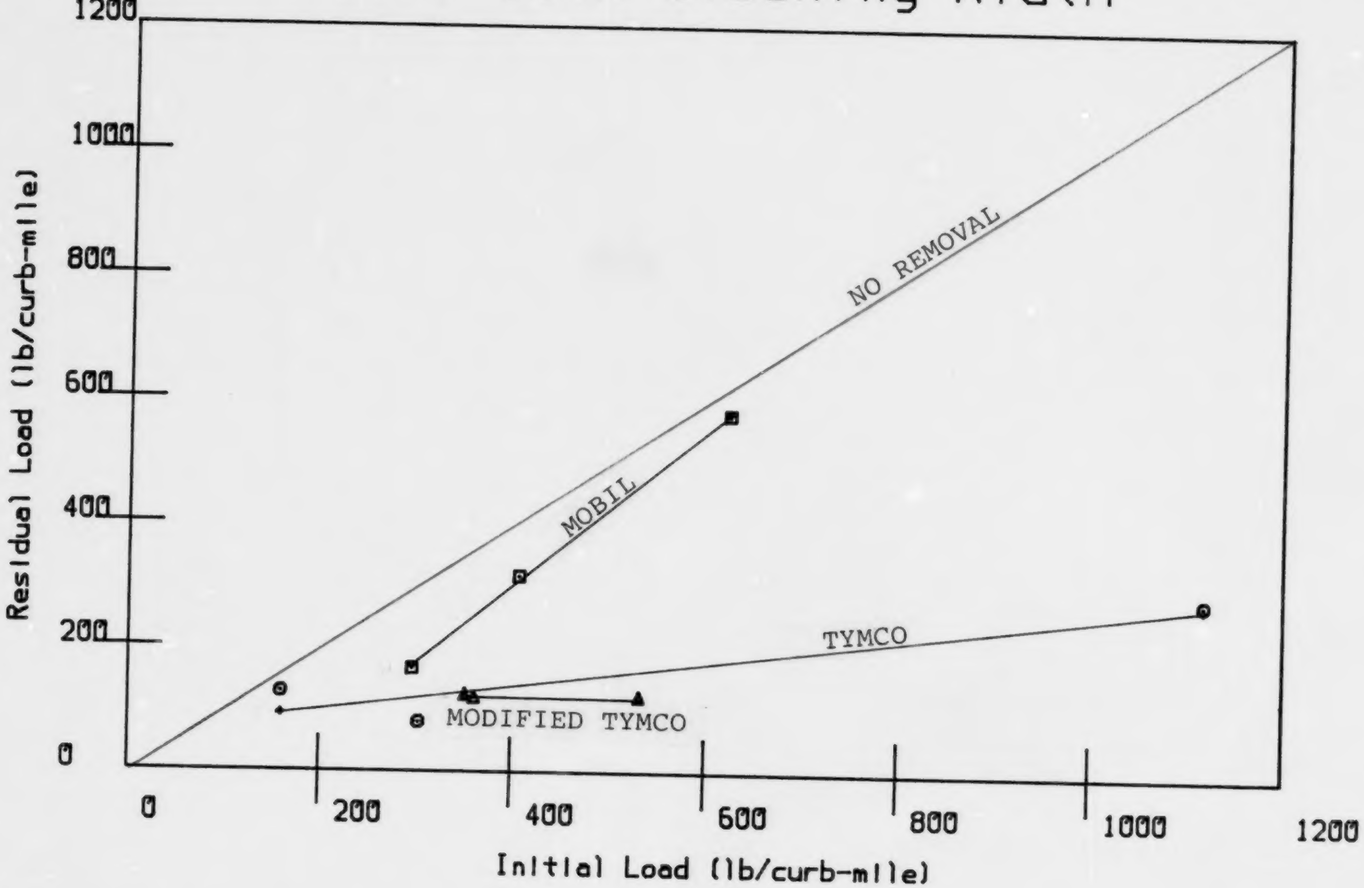
FIGURE 10-11

S.E. 30th Cleaning Width



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air street cleaner. This difference is not apparent with the full street width data.

Typical initial and residual loadings for these tests are shown in the bar charts, Figures 10-12 and 10-13. The modified regenerative air street cleaner is shown to have been more effective than the other street cleaners for almost all particle sizes, and for either area. The largest differences were observed in the smaller particle sizes (less than 125 microns) in the S.E. 30th area.

Figures 10-2 and 10-4 (and Appendix Figures C-1 through C-8) have the Surrey Downs regenerative air data plotted along with the full-scale broom cleaner data. It is seen that the regenerative air street cleaners are more effective, especially at the lower initial loading values. Table 10-2 shows the minimum effective loading values for each type of street cleaner. The modified street cleaner data are not shown on this table because they had performance characteristics close to the standard regenerative air cleaner (when considering the data variations on these figures).

These data results are similar to the results found by Pitt and Shawley in Castro Valley, California (1981), where they compared a regenerative air street cleaner with a standard broom street cleaner. They found that the air cleaner performed better with lighter loads, especially for the finer material. However, the broom cleaner was found to perform better for heavier loads, especially for heavy litter and leaf loads. Pitt also compared vacuum street cleaners to broom street cleaners in San Jose, California (1979). He found no significant difference in performance of the several types of street cleaners tested under a wide variety of street conditions and cleaning frequencies. One model of a broom street cleaner did result in substantially more residual loading values that were larger than the initial values for very intensive cleaning on oil and screens streets (it appeared to be loosening the street pavement material).

Effects of Intensive Street Cleaning on Washoff Potential

Typical loading values for the different particle sizes are shown on Table 10-3 for periods of no cleaning and for periods of intensive cleaning. These values are averaged Lake Hills and Surrey Downs loadings during the complete project period. Total solids loadings averaged about 390 lbs/curb-mile (110 g/curb-meter) with no street cleaning. The frequent Bellevue rains were capable of keeping these smooth asphalt streets quite clean (when compared to typical loadings elsewhere on the West Coast for no cleaning periods). Intensive, three times a week, street cleaning reduced these loadings to about 290 lbs/curb-mile (80 g/curb-meter). The most significant loading reductions were in the large particle sizes. No loading reductions were noted for particle sizes less than 250 microns in size. The washoff estimates given in Section 9 were used to estimate the washoff potential associated with these loadings. These values are also shown on Table 10-3. The washoff potential changes between the no cleaning and intensive cleaning periods was from about 70 to 63 lbs/curb-mile (20 to 18 g/curb-meter), or a reduction of about seven lbs/curb-mile (two

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FIGURE 10-12

Loadings During Special Tests-Surrey Downs

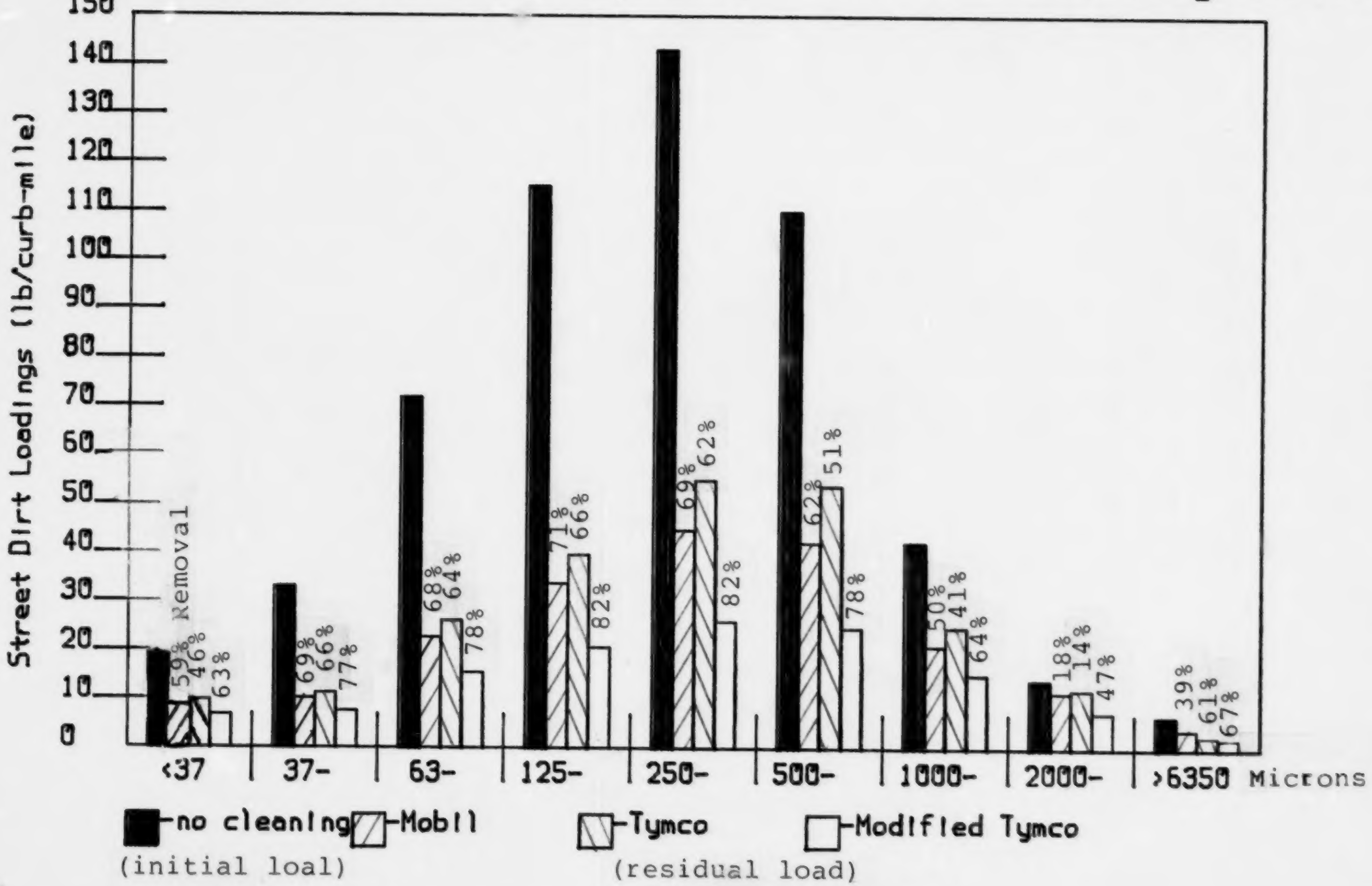

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FIGURE 10-13

Loadings During Special Tests-S.E. 30th

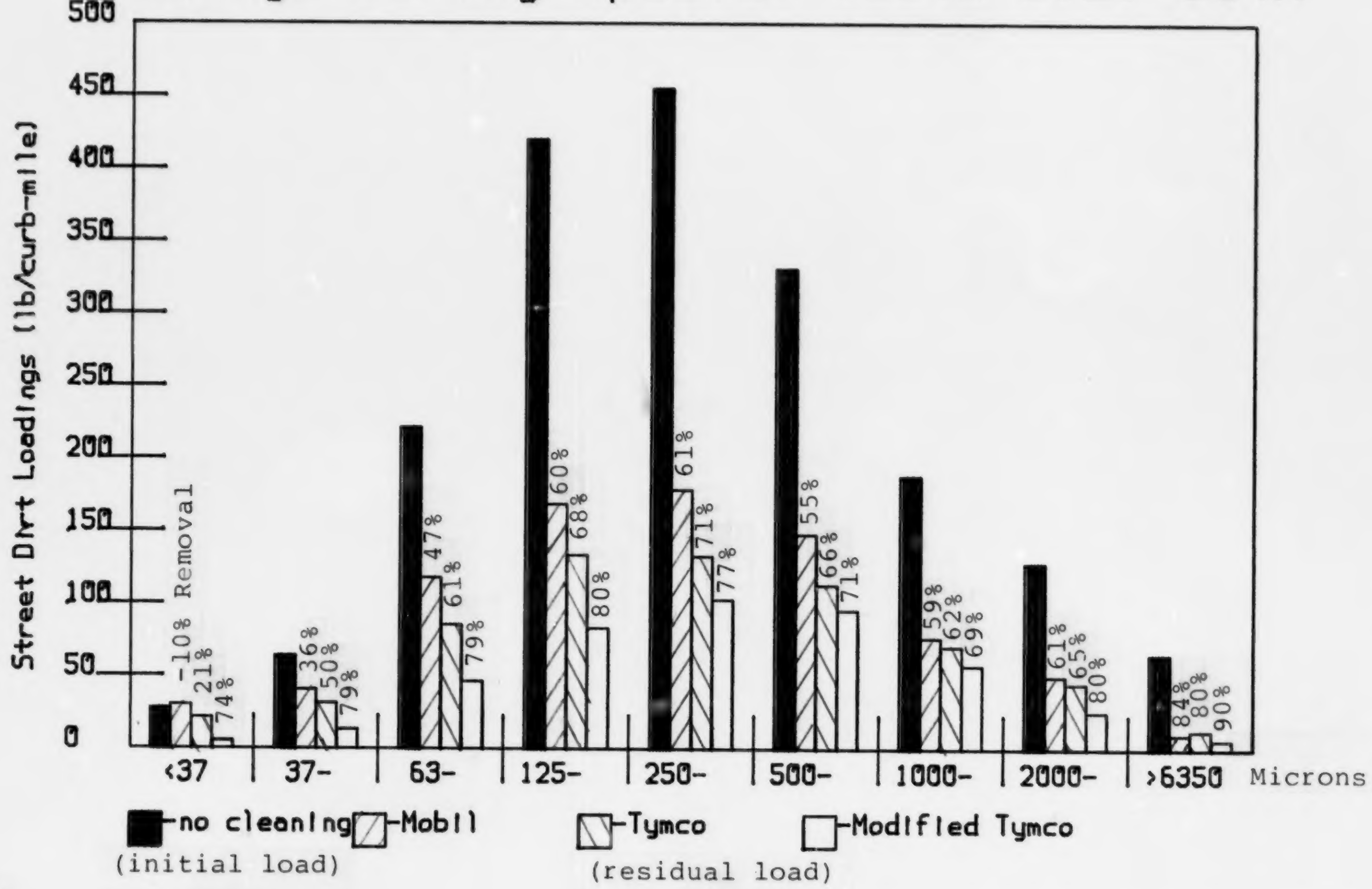

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TABLE 10-3. EFFECTS OF STREET CLEANING ON TOTAL STREET LOADS AND WASHOFF LOADS (LAKE HILLS AND SURREY DOWNS)

Particle Size (Microns)	No Cleaning				Intensive Cleaning			
	Typical Total Load		Available for Washoff		Typical Total Load		Available for Washoff	
	lb/curb mile	%of total in size	%of load for washoff	lb/curb mile	lb/curb mile	%of total in size	%of load for Washoff	lb/curb mile
> 6350	23.8	6.1%	0%	0	2.5	0.9%	0%	0
2000 - 6370	36.9	9.5	0	0	10	3.5	0	0
1000 - 2000	38.9	10.0	6	2.3	20	7.0	6	1.2
500 - 1000	68.3	17.5	10.5	7.2	56	19.5	10.5	5.9
250 - 500	81.1	20.7	17	13.8	60	20.9	17	10.2
125 - 250	64.8	16.6	24	15.6	62	21.6	24	14.9
63 - 125	38.4	9.9	38	14.6	38	13.3	38	14.4
< 63	37.9	9.7	44	16.7	38	13.3	44	16.7
Total solids	390	100.0%	18%	70.2	290	100.0%	22%	63.3

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g/curb-meter). Again, if the small particles were reduced more by street cleaning, the washoff potential would be reduced more.

Figure 10-14 graphically shows these load and runoff potential reductions. The percentage reductions are the same for both loads and runoff potential for sizes less than 2000 microns. Rain washes off very few of these larger particles. Street cleaning reduces the runoff potential for more particles in the size range of 250 to 500 microns than for any other size range. This figure shows that street cleaning has very little effect in removing the small particles that are most effectively washed off the street by rain.

Table 10-4 shows estimates of the effectiveness of street cleaning in reducing runoff yields of various pollutants. For very small rains, streets contribute about 60 to 65 percent of the total runoff yield for these pollutants. For larger storms, other source areas are more important than streets and the street contributions are reduced (except for lead which mostly originates from streets during all rains). The runoff yield reduction estimates are about six percent for the smallest storms, and about one to six percent for the larger storms. The modified regenerative air street cleaner may have removals about 1.25 times these values, or up to about eight percent. With such small potential benefits, it is obvious why the runoff monitoring activities did not result in any monitored reductions. It is expected that other areas, with less frequent rains, would have greater runoff potential reductions. Pitt and Shawley found runoff reductions associated with street cleaning as great as 40 percent in Castro Valley, California (1981). Castro Valley has less rain than Bellevue, but more importantly, it has long dry summers that result in very dirty streets if there is no street cleaning. These dirty streets can be effectively cleaned in late summer before the beginning of the rain season in Castro Valley. The different rain seasons in Bellevue are not as dramatic, and the streets never become so dirty without street cleaning.

BELLEVUE STREET CLEANING ROUTES, OPERATING CHARACTERISTICS, AND COSTS

There are no formal street cleaning routes in Bellevue. The city is usually divided at 8th Avenue NE, with one street cleaner operating north and the other street cleaner operating south of this street. The operators clean in areas that they feel require cleaning. They estimate that the downtown area is cleaned about once a week, arterials are cleaned about once a month, and residential areas are cleaned once every two months. The operators are radio dispatched to trouble areas, as needed. An interim storage area for the debris is located about two blocks from the municipal service center (where the street cleaners are stored). About nine cubic yards (seven cubic meters) per day per street cleaner is handled during the winter (about double this amount if the streets are sanded). During the spring and summer months, the debris quantity is reduced to about six cubic yards (4.5 cubic meters) per day per street cleaner. The fall is the heaviest debris period, with about 20 to 25 cubic yards (15 to 19 cubici meters) per day per street cleaner handled. About ten to fifteen percent of the city streets are rough, or have

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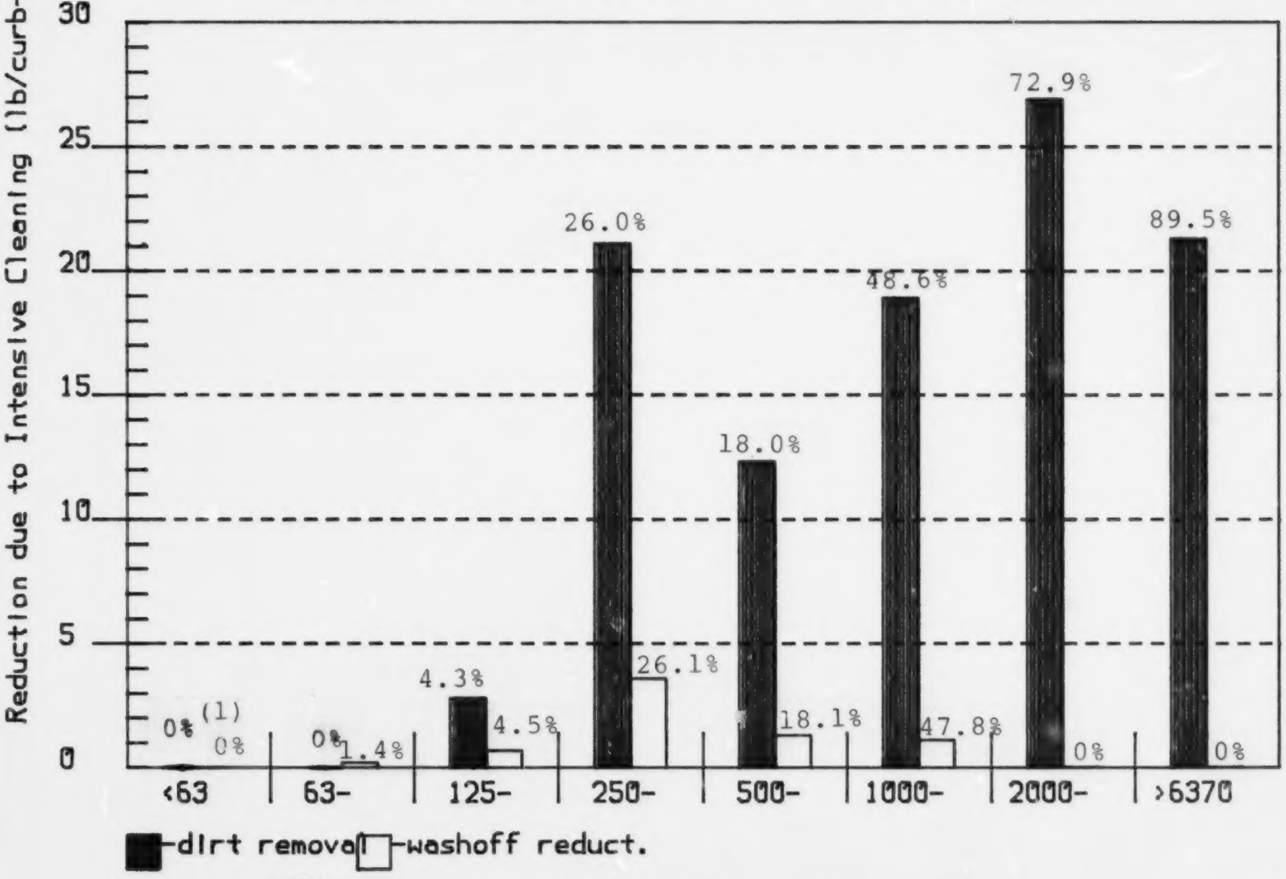
FIGURE 10-14

Load and Runoff Reductions



(1) Percent reduction when intensive cleaning is compared to no cleaning.

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Table 10-4. EFFECTS OF STREET CLEANING ON RUNOFF LOADS(1)

Runoff Pollutant	Approximate percent of total runoff load from street washoff		Percent runoff load reduction for intensive street cleaning	
	0.01 in. rain	≥0.1 in. rain	0.01 in. rain	≥0.1 in.
Total Solids	65%	10%	6.4%	1%
COD	62	40	6	4
Phosphates	61	31	6	3
Total Kjeldahl Nitrogen	61	31	6	3
Lead	60	60	6	6
Zinc	61	45	6	4.5

(1) The values shown are based on the 4-wheel mechanical street cleaner tests. The regenerative air street cleaners are estimated to be about 1.25 times as effective as the above values, due to their better performance on removing the more washable fine particles.

no curbs, or both.

The city of Bellevue has two street cleaners that are described on Table 10-5. They are both four-wheel mechanical broom cleaners, with dual gasoline engines, and 3.5 cubic yard (2.7 cubic meter) hoppers. They clean between 15 and 18 miles (24 and 29 km) each day, while cleaning at seven miles (11 km) per hour. During special tests in Reno and Sparks, Nevada, Pitt and Sutherland (1982) found that seven miles (11 km) per hour cleaning speeds were much less effective than the usually recommended four miles (6.5 km) per hour cleaning speeds. This was especially important at heavy loadings (greater than 1500 lbs/curb-mile, or 430 g/curb-meter). The current Bellevue street cleaning program productivity may therefore be improved by reducing the vehicle speeds, but at an increase in cost (if the cleaning frequency remains the same). The speed effects may not be as important in Bellevue because of the lower street dirt loadings, however. Reducing the speeds on the dirtier industrial streets may be worthwhile.

The street cleaners are maintained on a daily schedule, with appropriate inspections and lubrications. The main pick-up broom is changed about every 1400 to 1500 miles (400 to 425 km). Oil changes and other maintenance operations are also conducted during broom changes. The street cleaners are in the repair shop about 25 to 50 percent of the time. This downtime is about average for street cleaners elsewhere.

Bellevue street cleaning costs are shown on Table 10-6. Street cleaning is a labor intensive activity, with about 73 percent of the total street cleaning costs associated with labor and labor overhead. The total cost is about $20 per curb-mile ($12.50/curb-meter). Most of this cost is associated with operation activities, and about one-fifth is associated with both maintenance and debris disposal operations. Table 10-7 compares these Bellevue street cleaning costs with street cleaning costs for other western U.S. cities. The Bellevue costs are quite close to the total costs at these other cities.

Table 10-5. BELLEVUE STREET CLEANER OPERATING CHARACTERISTICS

Make of Equipment: Mobil Athey

Models: 2TE3, 4-wheel mechanical broom sweeper (1971)
2DF3, 4-wheel mechanical broom sweeper (1973)

Engine type: dual gasoline engines, with hydraulic controls

Hopper capacity: 3½ yds^3

Fuel Efficiency: 35-40 miles/day (including travel)
17-20 gal (both engines operating)
= 2.1 miles/gal

Sweeping miles: 15-18 miles/day

Debris disposal practices: interim storage area with separate transfer to land-fill as required

Speed during cleaning: 7 mph

Type of gutter broom: steel

Type of main pick-up broom: polyethylene

Broom replacement intervals: main broom 1400 sweeping miles
gutter broom 300 sweeping miles

Broom rotation speeds: unknown

Strike pressure of main pick-up broom: 4" pattern

Maintenance schedules:

1. "A" service - when main broom is changed, approximately every 1400-1500 sweeping miles, engine oil change, chassis lube
2. Daily - refuel, inspection lube conveyor chains and bearings
3. As needed, especially at broom changes

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Table 10-6. BELLEVUE STREET CLEANING COSTS (1980 - 1982)

Item	Typical Cost per year ($/year)	Percentage of total costs (%)	Unit Cost ($/curb-mile)
Labor:			
Repair labor	$10,780	8.3%	$1.68
Disposal labor	9,130	7.0	1.42
Operator labor	61,280	46.8	9.49
Labor overhead	14,210	10.9	2.21
Equipment operation, maintenace, disposal, etc.:			
Depreciation	5,300	4.1	0.83
Disposal equipment	12,400	9.5	1.93
Outside services	675	0.5	0.10
Repair parts (includes brooms)	10,240	7.8	1.58
Tires	710	0.5	0.10
Oil	120	0.1	0.02
Gasoline	5,890	4.5	0.91
Total	$130,735 per year	100%	$20.27 per curb mile

Sub-totals:

All labor and overhead: 73.0%

All maintenance (labor, outside services, and repair parts): 18.1%

All disposal (labor and equipment): 17.7%

All operaton (labor, depreciation, tires, oil and gasoline): 64.2%

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Table 10-7 STREET CLEANING COSTS AT VARIOUS CITIES (1982/1983 ADJUSTED COSTS)

	Bellevue, WA		San Jose, CA(1)		Alameda County, CA(2)		Reno, NV(3)		Sparks, NV(3)	
	$/Cleaned Mile	Percent of total	$/Cleaned Mile	Percent of total	$/Cleaned Mile	Percent of total	$/Cleaned Mile	Percent of total	$/Cleaned Mile	Percent of total
Labor										
Operators	$ 9.49	47%	$ 9.53	41%	-	-	$3.25-$5.50	18-19%	$ 3.28	16%
Maintenance and repair	1.68	8	5.35	23	-	-	0.94- 1.58	5	0.22	1
Supervisors	-(In overhead)-		2.32	10	-	-	0.59- 1.00	3	1.10	5
Debris transfer	1.42	7	-(Under disposal)-		-	-	0.20- 0.34	1	0.20	1
Overhead (secretary, dispatcher, etc.)	2.21	11	-(Included above)-		-	-	0.20- 0.34	1	0.46	2
Subtotal	14.80	73	17.20	74	$13.47	71%	5.18- 8.76	28-30	5.26	25
Street cleaning equipment										
Depreciation	0.83	4	0.70	3	0.64	3	-	-	-	-
Maintenance and repair	1.68	8	2.79	12	3.52	19	-	-	-	-
Operation (fuel, etc.)	1.03	5	0.70	3			-	-	-	-
Subtotal	3.54	17	4.19	18	4.16	22	11.12-18.80	61-64	13.32	65
Disposal (includes labor)										
Transferring and hauling equipment	1.93	10	-	-	-	-	2.00 (est.)	11	2.00 (est.)	10
Landfilling fees	-	-	-	-	-	-	(4)	-	-	-
Subtotal	1.93	10	1.86	8	1.35	7	2.00	11-7	2.00	10
Total	$20.00	100%	$23.00	100%	$19.00	100%	$18.00-$30.00	100%	$21.00	100%

Sources:

(1) Pitt, 1979
(2) Pitt and Shawley, 1981
(3) Pitt and Sutherland, 1982
(4) Alameda County reported a landfilling fee of $8.50 per cubic yard of street dirt to be disposed. If 0.13 cubic yards/curb mile are removed (as reported by Reno for the core area), this would be about $1.10 per mile cleaned. For 0.48 cubic yards/curb mile removed (Reno residential area), this would be about $4.00 per curb mile for landfill fees.

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SECTION 11

EFFECTS OF STORM DRAINAGE PARTICULATES ON RUNOFF QUALITY

The role of storm drainage particulates in urban runoff discharge and control was investigated during this Bellevue project. As described in Section 8, samples were periodically obtained from catchbasin sumps and storm drainage sewerage during the course of the two-year project. An indication of quantity and quality of storm drainage particulates was, therefore, obtained. Increases in catchbasin sump contents from the initial cleaning through the project period were used to estimate both the quantity of material that can be accumulated in the sumps and the best catchbasin cleaning frequency. The data obtained were also useful in estimating the role of catchbasin and storm drainage particulates in contributing to urban runoff pollutants and how catchbasin cleaning or storm sewerage cleaning practices may improve urban runoff quality.

Catchbasin sediment is mostly made up of street surface particulates that have been removed from the street surface during rain events and were accumulated in the sumps instead of being discharged at the outfall. Table 11-1 compares the chemical characteristics of eight different particle sizes for the street surface samples and the catchbasin samples. The data for the street surface samples represent the full two-year project period during both wet and dry seasons. The catchbasin samples, however, represent fewer samples and may be biased for the wet season. Even with possible differences in sampling times, it is seen that the catchbasin sediment chemical characteristics agree well with the chemical characteristics of the street dirt. These common chemical characteristics imply a strong association between the catchbasin sediments and street surface particulates. Because the average interevent time between rains in Bellevue is only five days, major chemical changes in catchbasin sediment quality may not be as important as in other locations having long dry periods between rains.

When the total sediment chemical characteristics are compared with the total street surface chemical characteristics, differences are much more pronounced. Table 11-2 compares relative constituent concentrations (mg constituent/kg total solids) for street dirt, catchbasin sediment, catchbasin supernatent, and runoff. The large differences in catchbasin sediment and street dirt are associated with the differences in particle size distributions. Even though the individual particle sizes have very similar chemical characteristics, the different particle size distributions are quite different, so that the overall mass characteristics are different, as shown on Table 11-2.

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Table 11-1. COMPARISON OF STREET DIRT AND CATCHBASIN CHEMICAL QUALITY BY PARTICLE SIZE (mg/kg)

	Particle Size (Microns)							
	<63	63-125	125-250	250-500	500-1000	1000-2000	2000-6350	>6350
Surrey Downs								
COD:								
Main basin	180,000	150,000	100,000	94,000	130,000	190,000	170,000	280,000
WHR	190,000	190,000	150,000	150,000	170,000	280,000	300,000	380,000
108th	150,000	100,000	54,000	36,000	37,000	37,000	55,000	70,000
catchbasins	157,000	130,000	91,600	100,000	143,000	245,000	272,000	244,000
TKN:								
Main basin	2900	2600	1700	1300	1400	1600	1200	1500
WHR	3300	3300	2300	1700	1900	2500	2400	1800
108th	1800	1200	970	410	460	340	290	350
catchbasins	2910	2070	1500	1600	1580	2600	2450	2050
TP:								
Main basin	830	610	470	420	480	690	750	740
WHR	810	680	470	520	530	580	640	620
108th	690	510	330	300	380	620	640	620
catchbasins	880	690	630	610	550	930	1060	760
Lead:								
Main basin	1400	1200	1100	840	680	420	240	280
WHR	440	330	250	180	160	320	50	80
108th	1600	1400	1400	910	570	240	130	90
catchbasins	1170	870	620	560	540	540	480	290
Zinc:								
Main basin	320	260	210	170	160	120	110	100
WHR	180	140	100	80	75	100	75	85
108th	270	210	160	120	130	130	100	150
catchbasins	395	320	195	200	200	230	190	150
Lake Hills								
COD:								
street dirt	230,000	180,000	110,000	100,000	210,000	240,000	270,000	420,000
catchbasins	230,000	170,000	140,000	140,000	240,000	280,000	250,000	190,000
TKN:								
street dirt	3500	3200	1900	1600	2300	2100	2000	3200
catchbasins	3600	2700	2000	2100	3000	3400	2300	2100
TP:								
street dirt	940	740	550	440	570	760	740	750
catchbasins	900	730	700	610	830	1600	1500	1800
Lead:								
street dirt	1900	1900	1700	1300	900	630	350	210
catchbasins	2000	1600	1300	920	910	820	620	440
Zinc:								
street dirt	370	330	270	220	180	180	130	140
catchbasins	520	390	290	260	300	290	300	350

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Table 11-2. COMPARISON OF RELATIVE CONCENTRATIONS
(mg constituent/kg total solids)

	COD	TKN	TP	Pb	Zn	Total Solids conc. (mg/1)
Surrey Downs						
runoff	405,000	9300	2100	2900	1100	110
catchbasin supernatant	190,000	8200	8400	1290	850	680
catchbasin sediments	250,000	1230	1690	3400	720	---
street dirt	145,000	1600	575	745	170	---
Lake Hills						
runoff	390,000	9500	2600	1600	1060	110
catchbasin supernatant	470,000	20,000	5200	1300	2000	120
catchbasin sediments	75,000	700	750	610	210	---
street dirt	190,000	2300	640	1170	230	---

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Table 11-2 can also be used to indicate the importance of different sources to the total urban runoff yield. Unfortunately, it is not possible to obtain a good particle size distribution of the urban runoff particulates and, especially, associated chemical characteristics for each urban runoff particle size. The urban runoff relative concentrations (mg constituent/kg total solids) for the complete runoff samples are quite different from most of the other samples. This, however, implies preferential washoff of the finer particulates; the less polluted larger particulates do not wash off of the street surfaces or other potential pollutant source areas as well as the finer particulates (as discussed in Section 9). The larger particulates are also more effectively accumulated in catchbasin sumps or in the storm drainage than the finer particulates.

It is clear that most of the catchbasin sediments are street surface particulates that have been washed off the street during rain events but have not been discharged to the outfall. Table 11-3 compares the estimated catchbasin sediment accumulations of different urban runoff pollutants with the street dirt accumulations and total urban runoff flow discharges. It is interesting to note that the total urban flow unit area discharges are in the same order of magnitude as the total street dirt and catchbasin sediment accumulations. The catchbasin sediment accumulation values are the rates observed after initial cleaning, before the stable volumes were obtained. A larger catchbasin sediment accumulation rate may be expected because of the possible flushing effects of rains during this period of time. The catchbasin sediment discharge values shown on this table are therefore minimum values and could easily be greater.

Street dirt accumulation values do not totally contribute to the urban runoff discharges. It has been shown in previous sections that not all of the street dirt is washed off the street. Some washed off street dirt is also accumulated in sewerage or catchbasins for indefinite periods of time. In addition, some of the street surface particulates are lost to the air due to fugitive dust emissions caused by winds or traffic-induced turbulence. Those particulates settle out on adjacent areas, or the finer particulates can remain suspended for some time. The amount of street dirt particulates that are lost to the air as fugitive emissions are quite small for the Bellevue area when compared to more arid areas. The short interevent periods do not allow the street surface particulate loadings to become very large and more exposed to the winds. The amount of material lost to the air is calculated based on the deposition rate minus the accumulation rate. As the interevent period increases (to greater than four or five days, or the typical interevent period) the amount of material lost to the air becomes important. These losses do not become very large until after about ten to twenty days of accumulation, which would be quite rare and would only occur several times a year during the dry season.

If a very large storm occurred that was capable of removing "all" of the particulates from the street surface and totally flushing the catchbasin sediments and sewerage sediments, the resultant urban runoff discharge may be very large. The erosion yield during a storm of this size would also be extremely large. Table 11-4 shows typical loadings that can occur at any one time in the Surrey Downs and Lake Hills areas that would potentially wash off

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Table 11-3. DISCHARGES AND ACCUMULATIONS IN URBAN AREAS

	Annual Discharge or Accumulation (lb/acre/yr)					
	Total Solids	COD	TKN	TP	Pb	Zn
Surrey Downs						
storm runoff	180	79	1.6	0.35	0.23	0.21
baseflow	100	10	0.53	0.10	0.03	0.053
total urban flow	280	89	2.1	0.45	0.26	0.26
street dirt (accumulation)(1)	170	22	0.2	0.1	0.1	0.03
street dirt (washoff)(2)	27	3	0.04	0.02	0.02	0.006
street dirt (fugitive losses(3)	15	2	0.02	0.01	0.01	0.003
catchbasin sed. (accumulation)(4)	130	33	0.16	0.22	0.44	0.10
Lake Hills						
storm runoff	250	100	2.4	0.61	0.4	0.27
baseflow	67	8.7	0.18	0.035	0.02	0.024
total urban flow	320	110	2.6	0.65	0.42	0.29
street dirt (accumulation)(1)	310	60	0.7	0.2	0.4	0.07
street dirt (washoff)(2)	56	10	0.14	0.04	0.1	0.02
street dirt (fugitive losses(3)	17	3	0.04	0.01	0.02	0.004
catchbasin sed. (accumulation)(4)	88	6.6	0.06	0.07	0.05	0.02

(1) Using average 2-5 day accumulation periods and appropriate rates

(2) See Table 9-4

(3) Calculated based on deposition rate minus accumulation rate times average interevent period, by month (fugitive dust loses to the air).

(4) See Table 8-8

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Table 11-4 TYPICAL LOADINGS AT ANY ONE TIME, POSSIBLY AVAILABLE FOR WASHOFF DURING MAJOR EVENTS (lb/acre)

	Total Solids	COD	TKN	TP	Lead	Zinc
Surrey Downs						
street dirt (5 days)	20	3	0.02	0.01	0.01	0.004
catchbasin sediments	100	25	0.13	0.13	0.4	0.08
sewerage sediments	13	3	0.02	0.02	0.05	0.01
average runoff event observed	2.7	1.0	0.022	0.005	0.004	0.003
maximum runoff event observed	38	8.9	0.27	0.06	0.04	0.03
Lake Hills						
street dirt (5 days)	21	4	0.05	0.01	0.03	0.005
catchbasin sediments	140	12	0.1	0.1	0.1	0.02
sewerage sediments	61	5	0.04	0.05	0.04	0.01
average runoff event observed	2.2	0.8	0.02	0.006	0.003	0.002
maximum runoff event observed	15	4.4	0.14	0.07	0.02	0.015

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during a very large event. Typical loadings are shown for street dirt, catchbasin sediment, and sewerage sediment. In addition, the maximum and average event runoff yield loadings that were observed are shown for comparison. The maximum runoff event that was monitored during the two-year study period was very large and would only occur several times in a decade in Bellevue. The maximum observed runoff event discharge is still only about ten to twenty-five percent of the total pollutants that are residing on the street surfaces, in the catchbasins, and in the sewerage. Therefore, urban runoff pollutants are definitely not source limited in Bellevue. Of course, the more available finer particle sizes which are also more heavily polluted are more limited in availability and may affect the potential storm yields for the large events. As noted in Section 6, only about ten percent of the total solids urban runoff discharge is expected to be associated with street surface particulates. This value increases to about 50 percent for lead for most storms. Section 9 estimates that only about 15 percent of the street surface particulates may wash off the street. The average urban runoff event in Lake Hills and Surrey Downs only discharges between two and three pounds of dirt per acre (2.3 and 3.4 kg/ha). The total solids street dirt loadings were about ten times this value. About half of the total annual urban runoff discharge may be residing on the street surfaces and tied up in catchbasin and storm drainage sediments at any one time. If the Bellevue rain events were capable of removing much of this material, then the urban runoff discharge yields would be much greater than monitored.

It is obvious that it is most important to preferentially remove the finer, more heavily polluted and more available materials before the rain events occur. As shown in Section 10, normal street cleaning equipment is not capable of effectively removing these finer, more polluted particles. The sediments in the catchbasins and the sewerage are mostly made up of the larger particles that do get washed off the street. These sediments have a much smaller median particle size than the street surface particulates. Catchbasin or sewerage cleaning can remove large quantities of these more potentially polluting particulates than the normal street cleaning operations. Catchbasin and storm drainage sediments, however, may not contribute large quantities of pollutants to the total urban runoff discharge, except for very rare events. If the catchbasins are "full", they will have little effect on the runoff yields. Catchbasin sump sediments can be relatively conveniently removed to eliminate a major potential source of urban runoff pollutants. Because the catchbasin sediment accumulation rate is quite low, frequent cleaning of catchbasins would not be necessary. It is expected that cleaning catchbasins twice a year at the most would be sufficient.

The City of Bellevue is currently conducting a more comprehensive city-wide sampling program of catchbasin sediments and that information can be very useful in designing a catchbasin cleaning program.

It is not possible to currently estimate the effectiveness of catchbasin cleaning in controlling Bellevue's urban runoff. Because of its low frequency and because it has the ability to remove more of the potentially polluting sediments, it is probably more cost effective than street cleaning in improving urban runoff quality in Bellevue. Because of the varying amounts

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of material that are in the catchbasins at any time, certain catchbasins and stretches of sewerage are much more important potential scour sources than others. The drainage system located near the unguttered sections of Westwood Homes Road and 108th Street in the Surrey Downs basins were much more heavily loaded than the sewerage and catchbasins observed elsewhere in the study areas. The contributions of these local erosion sources to the storm drainage system, and probably to the outfall, may be significantly reduced by installing curbs and gutters.

Table 11-3 showed that catchbasin sediments that may accumulate in clean sumps may be a significant fraction of the urban storm runoff yield. Annual, or twice a year, cleaning may be capable of reducing these storm discharges by ten to 25 percent for lead and total solids, and between five and ten percent for the other pollutants studied (COD, TKN, TP, and Zn). Cleaning less frequently than about once a year would reduce these expected improvements. These removals would occur for about the first year after cleaning, then the constant-volume values would be obtained with little effect on the runoff yields until the next cleaning. Leaving the catchbasin "full", however, increases the chances of increasing the runoff yield during very large scouring events. Some pollutants may also be chemically charged by oxidation-reduction reactions in the catchbasins, and could be connected to more available, soluble, toxic forms before discharge. Therefore, it is recommended that the storm sewer inlets be cleaned at least annually.

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Table A-1. LAKE HILLS - RAIN DATA FOR STUDY PERIOD

Month	# of storm periods	total rain (in)	rain per storm (in)			duration per storm (hrs)			preceding dry period (hrs)			avg rain intensity (in/hr)			peak 30 min rain intensity (in/hr)		
			avg	min	max	avg	min	max	avg	min	max	avg	min	max	avg	min	max
Feb/1980[1]	6+	3.03+	0.51	0.10	1.44	18.6	3.7	49.5	39.5	9.0	130.4	0.027	0.020	0.033	0.09	0.02	0.14
March	8	3.13	0.39	0.12	1.05	19.1	6.0	43.1	35.9	6.0	61.4	0.023	0.009	0.058	0.14	0.04	0.30
April	7	3.22	0.46	0.07	1.32	12.7	0.4	33.7	85.9	7.7	187.5	0.052	0.024	0.168	0.14	0.04	0.22
May	8	1.21	0.15	0.04	0.50	6.6	0.07	16.0	78.4	7.1	388.9	0.023	0.008	0.040	0.06	0.02	0.12
June	8	2.32	0.29	0.04	0.72	8.7	0.8	31.4	82.7	7.7	218.8	0.062	0.005	0.133	0.13	0.02	0.28
July	3	0.52	0.17	0.09	0.28	9.0	3.4	17.3	140.1	55.0	198.8	0.022	0.016	0.026	0.073	0.04	0.10
August	7	1.31	0.19	0.04	0.63	4.7	0.5	12.4	156.7	12.5	436.4	0.064	0.006	0.142	0.18	0.02	0.58
September	7	1.92	0.27	0.10	0.57	8.7	3.5	17.7	92.5	18.8	201.3	0.038	0.014	0.089	0.13	0.04	0.28
October	5	1.18	0.24	0.04	0.74	10.0	2.3	24.4	144.9	6.3	280.3	0.020	0.012	0.030	0.08	0.02	0.12
November	17	6.52	0.38	0.03	1.55	9.7	1.2	23.4	32.0	5.9	116.1	0.042	0.015	0.095	0.16	0.02	0.42
December	14	6.51	0.47	0.03	1.28	12.9	0.1	30.0	39.6	5.6	136.7	0.036	0.008	0.074	0.14	0.04	0.30
Ttl 1980[2]	90(+)	30.9(+)	0.34	0.03	1.55	11.0	0.07	49.5	84.4	5.6	436.4	0.037	0.006	0.168	0.12	0.02	0.58
Jan/1981	10	2.08	0.21	0.03	0.48	9.4	1.0	32.2	55.3	10.9	209.0	0.025	0.013	0.058	0.07	0.02	0.16
February	7	3.34	0.48	0.16	1.00	19.5	8.0	38.8	71.2	7.3	315.3	0.025	0.014	0.044	0.16	0.06	0.36
March	8	2.08	0.26	0.07	0.62	12.9	4.8	26.5	93.8	25.4	242.4	0.021	0.011	0.033	0.08	0.04	0.14
April	14	2.78	0.20	0.04	0.42	8.4	0.9	31.5	39.6	6.1	182.5	0.041	0.013	0.18	0.11	0.04	0.22
May	10	2.17	0.21	0.03	0.43	6.1	0.8	16.6	58.3	8.3	124.3	0.040	0.020	0.043	0.15	0.02	0.26
June	13	2.42	0.19	0.02	0.43	5.6	0.1	21.2	63.9	7.8	244.5	0.036	0.015	0.069	0.11	0.04	0.28
July	3	1.93	0.64	0.04	1.25	6.9	1.7	10.1	94.3	53.3	141.4	0.074	0.024	0.124	0.20	0.06	0.34
August	1	0.18	0.18	---	---	12.4	---	12.4	1150.8	1150.8	0.015	---	---	0.04	---	---	---
September	10	4.71	0.47	0.03	1.20	9.7	1.0	32.0	59.5	6.6	434.8	0.054	0.010	0.150	0.24	0.02	0.50
October	9	5.96	0.66	0.07	3.69	11.9	1.3	35.8	72.3	11.1	433.1	0.045	0.013	0.103	0.18	0.04	0.52
November	13	4.59	0.35	0.03	1.58	10.9	0.5	30.1	53.9	5.8	186.8	0.033	0.009	0.076	0.13	0.02	0.38
December	19	6.32	0.33	0.03	1.21	11.9	0.7	30.3	27.3	5.8	70.2	0.029	0.010	0.075	0.14	0.04	0.38
Ttl 1981	117	38.56	0.33	0.02	3.69	10.5	0.1	38.8	153.4	5.8	1150.8	0.037	0.010	0.18	0.13	0.02	0.52
Jan/1982	13	4.65	0.36	0.04	0.96	8.2	2.9	27.9	45.5	7.8	114.8	0.029	0.010	0.073	0.10	0.02	0.18
Ttl period	220	74.11	0.34	0.02	3.69	10.6	0.07	49.5	117.3	5.6	1150.8	0.037	0.006	0.18	0.12	0.02	0.58

(1) partial: start 2/15/80

(2) partial year

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Table A-2. SURREY DOWNS - RAIN DATA FOR STUDY PERIOD

Month	# of storm periods	total rain (in)	rain per storm (in) avg	min	max	duration per storm (hrs) avg	min	max	preceding dry period (hrs) avg	min	max	avg rain intensity (in/hr) avg	min	max	peak 30 min rain intensity (in/hr) avg	min	max
Mar/1980	11	3.19	0.29	0.04	1.11	11.5	4.3	29.4	54.8	5.9	157.1	0.027	0.009	0.062	0.12	0.02	0.24
April	10	3.00	0.30	0.02	0.28	8.9	1.2	30.8	60.2	5.6	189.2	0.037	0.008	0.089	0.15	0.02	0.28
May	6	1.35	0.23	0.04	0.60	13.5	0.7	30.3	98.3	9.9	372.3	0.024	0.008	0.057	0.08	0.04	0.16
June	7	2.85	0.41	0.08	0.72	11.2	1.7	31.4	88.2	7.2	194.7	0.049	0.008	0.088	0.15	0.02	0.22
July	4	0.48	0.12	0.03	0.22	7.6	2.2	13.5	132.8	34.0	196.8	0.016	0.010	0.022	0.05	0.02	0.08
August	6	1.39	0.23	0.06	0.63	5.7	1.5	17.2	160.0	14.2	354.9	0.051	0.009	0.078	0.18	0.02	0.50
September	7	1.89	0.27	0.08	0.50	9.4	3.3	17.5	95.3	18.8	199.5	0.033	0.010	0.064	0.15	0.04	0.30
October	5	1.24	0.25	0.03	0.74	11.7	2.3	25.1	143.1	94.5	184.4	0.019	0.008	0.029	0.09	0.04	0.18
November	13	6.79	0.52	0.05	1.66	16.4	3.2	56.5	37.4	5.8	111.9	0.036	0.009	0.103	0.17	0.04	0.46
December	13	6.44	0.50	0.03	1.28	14.8	1.1	31.4	41.5	6.9	137.1	0.032	0.008	0.071	0.13	0.02	0.30
Ttl 1980[1]	82+	28.62+	0.35	0.02	1.66	11.1	0.7	56.5	91.2	5.6	354.9	0.032	0.008	0.103	0.13	0.02	0.50
Jan/1981	10	2.26	0.23	0.04	0.63	9.5	1.5	32.2	57.9	9.1	208.7	0.025	0.013	0.041	0.07	0.02	0.14
February	5	3.21	0.64	0.16	1.05	28.3	6.3	71.8	99.1	13.3	317.1	0.026	0.015	0.040	0.18	0.06	0.42
March	8	1.96	0.25	0.07	0.62	12.3	3.4	26.5	87.7	19.4	266.4	0.022	0.011	0.033	0.08	0.04	0.14
April	11	2.20	0.20	0.08	0.38	9.9	2.3	26.2	50.1	10.0	180.8	0.034	0.011	0.119	0.11	0.04	0.32
May	11	1.81	0.17	0.04	0.33	5.4	1.8	8.9	53.3	5.3	125.0	0.033	0.008	0.091	0.11	0.02	0.26
June	10	1.90	0.19	0.03	0.33	5.4	0.6	18.3	82.4	9.3	287.8	0.048	0.013	0.092	0.13	0.04	0.28
July	3	1.86	0.62	0.16	1.17	7.3	2.6	10.2	94.3	53.4	141.8	0.078	0.058	0.115	0.23	0.16	0.30
August	1	0.24	0.24	---	---	13.4	---	---	1150.1	---	1150.1	0.018	---	---	0.08	---	---
September	7	3.47	0.50	0.05	1.22	15.2	0.4	39.8	77.8	6.8	386.8	0.053	0.022	0.055	0.23	0.04	0.40
October	8	6.57	0.82	0.07	4.38	12.0	1.2	34.1	82.8	8.3	432.6	0.052	0.013	0.128	0.20	0.04	0.64
November	14	4.62	0.33	0.03	1.50	10.1	1.0	28.5	26.5	5.9	167.0	0.037	0.009	0.089	0.13	0.04	0.26
December	19	6.26	0.33	0.03	1.10	10.0	0.8	30.6	27.7	5.6	59.6	0.036	0.007	0.062	0.13	0.04	0.34
Ttl 1981	107	36.36	0.34	0.03	4.38	11.6	0.4	71.8	157.4	5.3	1150.1	0.039	0.007	0.128	0.14	0.02	0.64
Jan/1982	11	5.5	0.50	0.04	1.17	20.2	3.4	74.7	53.6	7.8	182.0	0.023	0.008	0.058	0.13	0.02	0.34
Ttl period	200	70.48	0.35	0.02	4.38	11.8	0.4	74.7	124.1	5.3	1150.1	0.035	0.007	0.128	0.14	0.02	0.64

(1) (partial year)

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Table A-3. Rain Data for Lake Hills and Surrey Downs for 1980

Date	LH Total Rain (in)	LH Duration (hrs)	LH Ave. Rain Int. (in/hr)	LH Peak 30-min intensity (in/hr)	SD Total Rain (in)	SD Duration (hrs)	SD Ave. Rain Int. (in/hr)	SD Peak 30-min intensity (in/hr)	LH/SD Total Rain Ratio	LH/SD Duration Ratio	SD-LH Start Time
3/3/80	.19	8.0	.02	.06	.22	19.9	.01	.06	.86	.40	1.25
3/10	.76	31.6	.02	.30	.49	18.8	.03	.16	1.55	1.68	.42
3/12	1.05	43.1	.02	.14	1.11	29.4	.04	.18	.95	1.47	.17
3/19	.27	16.7	.02	.06	.24	10.3	.02	.06	1.13	1.62	-.08
3/26	.21	20.8	.01	.22	.19	5.3	.04	.24	1.11	3.92	15.80
3/29	.12	6.5	.02	.06	.04	4.6	.01	.02	3.00	1.41	-.33
4/5	.52	28.9	.02	.16	.40	31.2	.01	.16	1.30	.93	-.08
4/8	.92	21.0	.04	.22	.57	8.0	.07	.28	1.61	2.63	-.33
4/14	.32	10.6	.03	.18	.13	2.7	.05	.08	2.46	3.93	.00
4/18	1.32	33.7	.04	.20	1.18	30.8	.04	.18	1.12	1.09	.08
4/28	.07	2.2	.03	.04	.25	2.8	.09	.20	.28	.79	-1.25
4/29	.07	.4	.18	.14	.03	1.2	.03	.04	2.33	.33	.25
5/20	.29	33.7	.01	.12	.31	30.3	.01	.16	.94	1.11	-6.33
5/22	.06	2.6	.02	.04	.06	7.5	.01	.04	1.00	.35	.16
5/24	.15	5.4	.03	.08	.23	20.6	.01	.06	.65	.26	.50
5/26	.50	16.0	.03	.12	.60	16.3	.04	.12	.83	.98	.17
5/27	.10	6.2	.02	.04	.11	5.8	.02	.04	.91	1.07	.58
6/1	.69	7.8	.09	.18	.67	7.6	.09	.22	1.03	1.03	.08
6/1	.06	.9	.07	.10	.72	14.2	.05	.20	.08	.06	.17
6/5	.17	22.2	.01	.02	.24	31.4	.01	.02	.71	.71	.17
6/8	.17	8.8	.02	.14	.13	8.5	.02	.10	1.31	1.04	.08
6/16	.32	2.4	.13	.28	.36	5.2	.07	.20	.89	.46	.08
6/24	.72	9.7	.07	.22	.65	10.0	.07	.22	1.11	.97	.25
6/25	.08	.8	.10	.10	.08	1.7	.05	.12	1.00	.47	-.75
7/4	.09	3.4	.03	.04	.08	7.8	.01	.04	1.13	.44	1.83
7/11	.28	17.3	.02	.08	.22	13.5	.02	.06	1.27	1.28	3.25
7/14	.15	6.4	.02	.10	.15	6.8	.02	.08	1.00	.94	-.25
8/2	.09	2.0	.05	.04	.07	1.7	.04	.04	1.29	1.18	.00
8/17	.63	9.2	.07	.58	.63	17.2	.04	.50	1.00	.53	-10.40
8/26	.04	.5	.08	.08	.08	1.5	.05	.12	.50	.33	-1.25
8/27	.17	1.2	.14	.28	.18	2.3	.08	.24	.94	.52	-.67
8/28	.26	2.6	.10	.22	.37	4.3	.09	.18	.70	.60	-.33
8/30	.04	5.1	.01	.04	.06	6.9	.01	.02	.67	.74	-.08
9/1	.57	17.7	.03	.14	.50	17.5	.03	.08	1.14	1.01	-.25
9/6	.23	4.2	.05	.22	.27	4.2	.06	.30	.85	1.00	-.58
9/12	.12	4.6	.03	.06	.08	3.8	.02	.04	1.50	1.21	-.08
9/13	.16	11.3	.01	.04	.14	13.4	.01	.04	1.14	.84	-.83
9/19	.10	3.5	.03	.04	.09	3.3	.03	.04	1.11	1.06	.25
9/20	.25	14.0	.02	.16	.38	15.9	.02	.30	.66	.88	-.50
9/29	.49	5.5	.09	.28	.43	7.4	.06	.24	1.14	.74	-.33
10/8	.11	9.1	.01	.12	.19	10.2	.02	.18	.58	.89	-.67
10/12	.16	15.7	.01	.08	.12	14.6	.01	.04	1.33	1.08	.08
10/24	.17	7.3	.02	.10	.16	6.2	.03	.10	1.06	1.18	-.08
10/31	.74	24.4	.03	.10	.74	25.1	.03	.10	1.00	.97	.00
11/1	.36	10.9	.03	.14	.29	13.5	.02	.14	1.24	.81	.58
11/2	.52	22.3	.02	.14	.60	24.1	.02	.12	.87	.93	-2.58
11/5	.35	3.7	.09	.24	.33	3.2	.10	.26	1.06	1.16	.67
11/6	1.45	55.8	.03	.24	1.59	56.5	.03	.30	.91	.99	.25

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Table A-3. Rain Data for Lake Hills and Surrey Downs for 1980 (cont.)

Date	LH Total Rain (in)	LH Duration (hrs)	LH Ave. Rain Int. (in/hr)	LH Peak 30-min intensity (in/hr)	SD Total Rain (in)	SD Duration (hrs)	SD Ave. Rain Int. (in/hr)	SD Peak 30-min intensity (in/hr)	LH/SD Total Rain Ratio	LH/SD Duration Ratio	SD-LH Start Time
11/9	.17	11.7	.01	.12	.22	12.8	.02	.14	.77	.91	.50
11/14	.15	4.9	.03	.08	.12	9.8	.01	.04	1.25	.50	-3.50
11/17	.03	1.2	.03	.02	.05	5.5	.01	.04	.60	.22	-1.67
11/19	.19	2.7	.07	.18	.21	3.2	.07	.12	.90	.84	-.17
11/20	1.55	23.4	.07	.42	1.66	22.3	.07	.46	.93	1.05	.25
11/25	.16	2.7	.06	.12	.15	5.8	.03	.10	1.07	.47	.08
11/27	.70	13.6	.05	.26	.71	17.8	.04	.22	.99	.76	-.25
11/28	.61	17.7	.03	.18	.66	21.0	.03	.18	.92	.84	-3.25
11/30	.24	14.9	.02	.06	.20	18.1	.01	.06	1.20	.82	-2.00
12/2	1.02	14.9	.07	.28	.97	15.2	.06	.20	1.05	.98	-.42
12/3	.66	31.0	.02	.18	.51	31.4	.02	.14	1.29	.99	-.08
12/10	.06	7.2	.01	.04	.04	5.1	.01	.02	1.50	1.41	.33
12/14	.17	5.8	.03	.12	.11	5.8	.02	.06	1.55	1.00	-.08
12/20	.43	11.4	.04	.14	.43	11.3	.04	.18	1.00	1.01	.25
12/21	.68	31.4	.02	.14	.73	24.1	.03	.16	.93	1.30	-.08
12/24	.73	30.0	.02	.20	.77	30.0	.03	.22	.95	1.00	-.08
12/25	1.28	17.3	.07	.30	1.28	18.0	.07	.30	1.00	.96	.00
12/26	.32	5.9	.05	.16	.34	6.6	.05	.16	.94	.89	-.58
12/29	.30	11.4	.03	.04	.30	12.0	.03	.06	1.00	.95	.08
12/30	.83	28.1	.03	.12	.84	23.9	.04	.14	.99	1.18	.25
sum	26.94	884.9	2.84	9.94	27.06	904.7	2.37	9.72	73.09	68.11	-11.33
average	.40	13.0	.04	.15	.40	13.3	.03	.14	1.07	1.00	-.17
minimum	.03	.4	.01	.02	.03	1.2	.01	.02	.08	.06	-10.40
maximum	1.55	55.8	.18	.58	1.66	56.5	.10	.50	3.00	3.93	15.80

Table A-4. Rain Data for Lake Hills and Surrey Downs for 1981

Date	LH Total Rain (in)	LH Duration (hrs)	LH Ave. Rain Int. (in/hr)	LH Peak 30-min intensity (in/hr)	SD Total Rain (in)	SD Duration (hrs)	SD Ave. Rain Int. (in/hr)	SD Peak 30-min intensity (in/hr)	LH/SD Rain Ratio	LH/SD Duration Ratio	SD-LH Start Time
1/6/81	.07	1.2	.06	.08	.05	1.5	.03	.02	1.40	.80	.08
1/8	.03	1.0	.03	.04	.04	3.1	.01	.04	.75	.32	-2.33
1/17	.06	4.6	.01	.04	.11	7.1	.02	.08	.55	.65	-.58
1/18	.09	7.0	.01	.04	.11	5.8	.02	.04	.82	1.21	.08
1/23	.48	14.7	.03	.16	.38	10.5	.04	.14	1.26	1.40	-1.75
1/27	.06	2.2	.03	.02	.09	4.5	.02	.04	.67	.49	-.42
1/28	.60	17.0	.04	.08	.63	15.3	.04	.10	.95	1.11	-.33
2/11	1.00	23.4	.04	.20	.91	22.7	.04	.18	1.10	1.03	-.17
2/17	.16	8.0	.02	.06	.16	6.3	.03	.06	1.00	1.27	.00
2/18	.58	18.8	.03	.36	.73	25.3	.03	.42	.79	.74	-1.92
3/24	.21	6.3	.03	.08	.26	7.9	.03	.08	.81	.80	-.25
3/28	.14	9.4	.01	.06	.18	11.1	.02	.06	.78	.85	-5.00
3/31	.32	11.7	.03	.08	.11	3.4	.03	.04	2.91	3.44	.33
4/2	.27	16.9	.02	.22	.23	18.0	.01	.12	1.17	.94	.08
4/5	.18	3.8	.05	.12	.16	2.3	.07	.12	1.13	1.65	1.08
4/6	.34	1.9	.18	.28	.38	3.2	.12	.32	.89	.59	-1.16
4/7	.28	20.0	.01	.06	.22	18.4	.01	.06	1.27	1.09	.25
4/10	.42	31.5	.01	.14	.34	26.2	.01	.12	1.24	1.20	.17
4/12	.12	6.7	.02	.08	.13	11.8	.01	.10	.92	.57	-5.16
4/20	.19	3.1	.06	.14	.08	3.6	.02	.04	2.38	.86	-1.67
4/21	.27	16.4	.02	.08	.11	10.1	.01	.06	2.45	1.62	.00
4/23	.08	2.4	.03	.06	.08	3.0	.03	.06	1.00	.80	-.41
4/27	.18	4.7	.04	.06	.15	3.3	.05	.06	1.20	1.42	1.34
4/27	.35	14.2	.02	.12	.32	9.5	.03	.12	1.09	1.49	-3.92
5/3	.29	4.4	.07	.22	.21	2.3	.09	.14	1.38	1.91	-.08
5/7	.33	16.6	.02	.16	.49	19.4	.03	.26	.67	.86	-1.67
5/9	.03	1.0	.03	.02	.05	4.0	.01	.04	.60	.25	-3.25
5/10	.39	6.1	.06	.26	.29	6.7	.04	.20	1.34	.91	-.16
5/14	.18	4.2	.04	.22	.05	1.8	.03	.06	3.60	2.33	-.33
5/18	.20	7.2	.03	.12	.15	8.9	.02	.06	1.33	.81	-1.16
5/19	.24	6.2	.04	.10	.22	6.2	.04	.10	1.09	1.00	.00
5/24	.03	.8	.04	.04	.04	4.9	.01	.02	.75	.15	-.50
5/24	.36	14.2	.03	.20	.31	18.3	.02	.10	1.16	.78	-3.25
6/4	.03	.8	.04	.04	.03	.7	.04	.04	1.00	1.07	.16
6/5	.43	6.2	.07	.16	.33	6.8	.05	.14	1.30	.91	-.17
6/8	.40	5.8	.07	.16	.31	5.1	.06	.12	1.29	1.14	.75
6/9	.08	4.0	.02	.06	.05	.6	.08	.08	1.60	6.67	3.58
6/12	.28	4.2	.07	.18	.23	2.5	.09	.22	1.22	1.68	.00
6/12	.21	6.7	.03	.12	.33	6.6	.05	.28	.64	1.02	-.17
6/15	.10	5.7	.02	.08	.11	6.5	.02	.04	.91	.88	-.08
6/17	.37	21.2	.02	.08	.23	18.3	.01	.08	1.61	1.16	5.42
6/30	.33	6.5	.05	.28	.25	5.7	.04	.24	1.32	1.14	.33
7/6	.64	8.8	.07	.20	.53	9.1	.06	.22	1.21	.97	-.17
7/10	.04	1.7	.02	.06	.16	2.6	.06	.16	.25	.65	-.42
7/13	1.25	10.1	.12	.34	1.17	10.2	.11	.30	1.07	.99	.58
8/31	.18	12.4	.01	.04	.24	13.4	.02	.08	.75	.93	-.08
9/1	.12	1.0	.12	.18	.06	.4	.15	.12	2.00	2.50	.50
9/18	.45	13.3	.03	.26	.45	13.3	.03	.26	1.00	1.00	.00

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Table A-4. Rain Data for Lake Hills and Surrey Downs for 1981(cont.)

Date	LH Total Rain (in)	LH Duration (hrs)	LH Ave. Rain Int. (in/hr)	LH Peak 30-min intensity (in/hr)	SD Total Rain (in)	SD Duration (hrs)	SD Ave. Rain Int. (in/hr)	SD Peak 30-min intensity (in/hr)	LH/SD Rain Ratio	LH/SD Duration Ratio	SD-LH Start Time
9/19	.10	1.8	.06	.14	.05	1.7	.03	.04	2.00	1.06	.17
9/20	1.05	32.0	.03	.26	.68	31.4	.02	.22	1.54	1.02	-.08
9/25	1.06	9.1	.12	.64	.58	10.6	.05	.28	1.83	.86	-.25
9/26	1.48	40.0	.04	.50	1.22	39.8	.03	.28	1.21	1.01	.34
9/28	.42	11.7	.04	.24	.43	9.1	.05	.40	.98	1.29	2.17
10/1	.76	8.5	.09	.36	.81	9.7	.08	.40	.94	.88	-.17
10/5	3.69	35.8	.10	.52	4.38	34.1	.13	.64	.84	1.05	.33
10/7	.10	6.0	.02	.10	.14	5.4	.03	.14	.71	1.11	-.17
10/8	.27	9.5	.03	.16	.24	9.7	.02	.10	1.13	.98	-.33
10/27	.73	27.2	.03	.14	.74	27.5	.03	.14	.99	.99	-.17
10/28	.11	1.3	.08	.10	.10	1.2	.08	.10	1.10	1.08	.00
10/29	.16	10.8	.01	.10	.07	5.2	.01	.04	2.29	2.08	-2.83
10/30	.07	2.8	.03	.06	.09	3.2	.03	.06	.78	.88	.00
11/11	1.58	20.7	.08	.38	1.50	20.2	.07	.26	1.05	1.02	.00
11/13	.14	9.0	.02	.10	.11	8.8	.01	.08	1.27	1.02	.25
11/14	.05	.5	.10	.10	.10	2.6	.04	.10	.50	.19	-2.83
11/14	.45	32.4	.01	.14	.36	25.4	.01	.12	1.25	1.28	.17
11/16	.53	18.0	.03	.16	.51	16.2	.03	.14	1.04	1.11	.16
11/19	.18	17.7	.01	.06	.20	16.4	.01	.08	.90	1.08	-.08
11/20	.03	1.8	.02	.02	.03	1.4	.02	.04	1.00	1.29	-.08
11/20	.88	30.1	.03	.20	.86	28.5	.03	.26	1.02	1.06	-.42
11/22	.35	5.3	.07	.14	.49	5.5	.09	.22	.71	.96	-.25
11/23	.21	4.8	.04	.22	.18	4.8	.04	.18	1.17	1.00	-.08
11/30	.09	10.5	.01	.04	.14	16.2	.01	.10	.64	.65	.50
12/1	.57	18.6	.03	.30	.55	18.6	.03	.24	1.04	1.00	.17
12/3	.16	14.1	.01	.08	.19	13.3	.01	.12	.84	1.06	.00
12/4	1.21	21.8	.06	.38	1.10	17.6	.06	.28	1.10	1.24	4.17
12/5	.22	15.5	.01	.06	.17	9.6	.02	.06	1.29	1.61	.75
12/6	.05	2.7	.02	.06	.05	5.2	.01	.06	1.00	.52	-4.08
12/9	.84	30.3	.03	.20	.78	30.6	.03	.16	1.08	.99	-.08
12/13	.30	8.9	.03	.16	.36	6.1	.06	.18	.83	1.46	-.75
12/17	.21	15.2	.01	.06	.29	15.2	.02	.08	.72	1.00	-.17
12/18	.69	19.3	.04	.20	.79	19.5	.04	.14	.87	.99	-.33
12/21	.09	1.2	.08	.10	.08	.8	.10	.12	1.13	1.50	.33
12/23	.26	11.0	.02	.10	.27	8.8	.03	.12	.96	1.25	3.50
12/24	.07	1.7	.04	.12	.09	1.7	.05	.12	.78	1.00	-1.08
12/26	.40	23.5	.02	.26	.45	22.2	.02	.34	.89	1.06	-.33
12/27	.07	6.7	.01	.04	.06	1.2	.05	.06	1.17	5.58	-.42
12/28	.10	8.0	.01	.08	.04	5.3	.01	.04	2.50	1.51	-3.17
12/30	.06	2.4	.03	.04	.03	4.5	.01	.04	2.00	.53	-1.17
sum	33.23	964.1	3.49	13.36	31.56	923.0	3.41	12.42	102.72	105.28	-28.14
average	.38	11.0	.04	.15	.36	10.5	.04	.14	1.17	1.20	-.32
minimum	.03	.5	.01	.02	.03	.4	.01	.02	.25	.15	-5.16
maximum	3.69	40.0	.18	.64	4.38	39.8	.15	.64	3.60	6.67	5.42

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Table A-5. Rain Data for Lake Hills and Surrey Downs for 1982

Date	LH Total Rain (in)	LH Duration (hrs)	LH Ave. Rain Int. (in/hr)	LH Peak 30-min intensity (in/hr)	SD Total Rain (in)	SD Duration (hrs)	SD Ave. Rain Int. (in/hr)	SD Peak 30-min intensity (in/hr)	LH/SD Rain Ratio	LH/SD Duration Ratio	SD-LH Start Time
1/10/82	.35	24.8	.01	.12	.30	24.0	.01	.12	1.17	1.03	.84
1/15	.98	27.9	.04	.14	1.10	28.7	.04	.16	.89	.97	.58
1/17	.18	12.8	.01	.10	.16	8.8	.02	.10	1.13	1.45	2.33
1/22	1.32	35.1	.04	.18	1.17	35.7	.03	.22	1.13	.98	-.58
1/25	.12	5.3	.02	.08	.13	5.2	.03	.10	.92	1.02	.17
1/25	.96	17.8	.05	.12	1.01	17.3	.06	.14	.95	1.03	-.16
1/27	.06	2.9	.02	.04	.07	5.8	.01	.04	.86	.50	-3.33
1/27	.04	4.2	.01	.02	.04	3.4	.01	.02	1.00	1.24	-1.25
1/30	.87	72.8	.01	.12	1.15	74.7	.02	.34	.76	.97	-1.83
sum	4.88	203.6	.22	.92	5.13	203.6	.22	1.24	8.80	9.20	-3.23
average	.54	22.6	.02	.10	.57	22.6	.02	.14	.98	1.02	-.36
minimum	.04	2.9	.01	.02	.04	3.4	.01	.02	.76	.50	-3.33
maximum	1.32	72.8	.05	.18	1.17	74.7	.06	.34	1.17	1.45	2.33

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Table A-6a. Surrey Downs Runoff Conditions for 1980

Runoff Start Date	Total Rain (Inches)	Rain Duration (hrs)	Average Rain Int. (in/hr)	Peak 30 Min Int. (in/hr)	Total Discharge (cubic feet)	Total Discharge (inches)	Runoff Duration (hours)	Peak Discharge (cfs)	Runoff Coefficient (Rv-ratio)	Runoff/Rain Duration (ratio)
3/3/80	.22	19.9	.01	.06	12500	.04	19.0	.68	.18	.95
3/10	.49	18.8	.03	.16	29000	.09	14.0	3.18	.18	.74
3/11	.17	4.3	.04	.24	10800	.03	5.9	2.93	.20	1.37
3/12	1.11	29.4	.04	.18	98700	.30	37.9	3.18	.27	1.29
3/14	.09	4.3	.02	.06	18600	.06	21.2	.99	.64	4.93
3/16	.18	19.7	.01	.04	14000	.04	15.6	.59	.24	.79
3/17	.35	5.6	.06	.22	26400	.08	13.9	2.68	.23	2.48
3/19	.24	10.3	.02	.06	16900	.05	11.8	1.19	.22	1.15
3/26	.19	5.3	.04	.24	8550	.03	5.7	3.18	.14	1.08
3/29	.04	4.6	.01	.02	1320	.00	1.2	.68	.10	.26
3/31	.11	4.6	.02	.04	5060	.02	4.8	.56	.14	1.04
4/5	.21	11.0	.02	.16	10900	.03	11.8	1.73	.16	1.07
4/5	.19	13.4	.01	.12	11700	.04	13.2	1.59	.19	.99
4/8	.04	5.0	.01	.02	1670	.01	3.2	.77	.13	.64
4/8	.57	8.0	.07	.28	35300	.11	11.2	4.76	.19	1.40
4/9	.22	7.5	.03	.18	13600	.04	9.2	2.93	.19	1.23
4/14	.13	2.7	.05	.08	5570	.02	3.1	.99	.13	1.15
4/14	.18	6.9	.03	.20	8590	.03	6.5	4.04	.15	.94
4/18	1.18	30.8	.04	.18	78800	.24	36.7	3.45	.21	1.19
4/28	.25	2.8	.09	.20	11000	.03	4.2	5.12	.14	1.50
4/29	.03	1.2	.03	.04	120	.00	1.2	.07	.01	1.00
5/15	.04	.7	.06	.04	157	.00	.3	.29	.01	.36
5/20	.31	30.3	.01	.16	20000	.06	29.9	2.27	.20	.99
5/22	.06	7.5	.01	.04	4580	.01	7.5	.46	.24	1.00
5/24	.23	20.6	.01	.06	10600	.03	20.2	1.26	.14	.98
5/26	.60	16.3	.03	.12	42100	.13	16.2	2.05	.22	.99
5/27	.11	5.8	.02	.04	6700	.02	4.8	.80	.19	.83
6/1	.67	7.6	.09	.22	37000	.11	9.1	2.88	.17	1.20
6/1	.72	14.2	.05	.20	55200	.17	16.9	3.44	.24	1.19
6/5	.24	31.4	.01	.02	10300	.03	30.6	.33	.13	.97
6/8	.13	8.5	.02	.10	4680	.01	1.9	1.83	.11	.22
6/16	.36	5.2	.07	.20	19400	.06	5.2	3.44	.17	1.00
6/24	.65	10.0	.06	.22	35200	.11	10.2	3.16	.17	1.02
6/25	.08	1.7	.05	.12	4090	.01	2.2	1.83	.16	1.29
7/4	.08	7.8	.01	.04	2100	.01	4.9	.29	.08	.63
7/11	.22	13.5	.02	.06	10700	.03	11.4	1.10	.15	.84
7/14	.15	6.8	.02	.08	6150	.02	6.5	.94	.13	.96
7/19	.03	2.2	.01	.02	560	.00	2.6	.16	.06	1.18
8/2	.07	1.7	.04	.04	2440	.01	2.1	.56	.11	1.24
8/17	.63	17.2	.04	.50	31800	.10	17.1	7.17	.16	.99
8/26	.08	1.5	.05	.12	2670	.01	1.2	1.35	.10	.80
8/27	.18	2.3	.08	.24	8450	.03	2.1	4.06	.14	.91
8/28	.37	4.3	.08	.18	23600	.07	5.2	3.89	.20	1.21
8/30	.06	6.9	.01	.02	920	.00	6.9	.11	.05	1.00
9/1	.50	17.5	.03	.08	31400	.10	18.3	1.63	.19	1.05
9/6	.27	4.2	.06	.30	11900	.04	2.9	3.89	.14	.69
9/12	.08	3.8	.02	.04	1970	.01	1.9	.46	.08	.50
9/13	.14	13.4	.01	.04	5020	.02	12.0	.33	.11	.90
9/19	.09	3.3	.03	.04	2870	.01	2.4	.51	.10	.73

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Table A-6a.Surrey Downs Runoff Conditions for 1980(cont.)

Runoff Start Date	Total Rain (Inches)	Rain Duration (hrs)	Average Rain Int. (in/hr)	Peak 30 Min Int. (in/hr)	Total Discharge (cubic feet)	Total Discharge (inches)	Runoff Duration (hours)	Peak Discharge (cfs)	Runoff Coefficient (Rv-ratio)	Runoff/Rain Duration (ratio)
9/20	.38	15.9	.03	.30	20300	.06	15.4	4.40	.16	.97
9/29	.43	7.4	.06	.24	23700	.07	6.7	3.30	.17	.91
10/8	.19	10.2	.02	.18	10200	.03	10.4	3.44	.17	1.02
10/12	.12	14.6	.01	.04	4280	.01	6.9	.62	.11	.47
10/20	.03	2.3	.01	.04	1390	.00	1.9	.51	.14	.83
10/24	.16	6.2	.03	.10	7760	.02	5.8	1.53	.15	.94
10/31	.74	25.1	.03	.10	48500	.15	24.5	1.73	.20	.98
11/1	.29	13.5	.02	.14	20700	.06	13.3	1.94	.22	.99
11/3	.60	24.1	.03	.12	41600	.13	22.1	2.38	.21	.92
11/5	.33	3.2	.10	.26	20400	.06	5.4	4.40	.19	1.69
11/6	1.59	56.5	.03	.30	126000	.39	55.9	5.34	.24	.99
11/9	.22	12.8	.02	.14	17200	.05	12.1	2.27	.24	.95
11/14	.12	9.8	.01	.04	5330	.02	5.2	1.26	.14	.53
11/17	.05	5.5	.01	.04	2510	.01	3.4	.37	.15	.62
11/19	.21	3.2	.07	.12	14200	.04	5.4	3.02	.21	1.69
11/20	1.66	22.3	.07	.46	130000	.40	27.8	7.17	.24	1.25
11/25	.15	5.8	.03	.10	8730	.03	5.4	1.73	.18	.93
11/27	.71	17.8	.04	.22	55100	.17	17.8	3.16	.24	1.00
11/28	.66	21.0	.03	.18	60000	.18	27.2	3.30	.28	1.30
11/29	.22	18.1	.01	.06	27900	.09	22.6	1.18	.39	1.25
12/1	.06	7.7	.01	.04	4920	.02	7.5	.74	.25	.97
12/2	.97	15.2	.06	.20	90900	.28	20.7	4.40	.29	1.36
12/3	.51	31.4	.02	.14	61200	.19	35.8	2.49	.37	1.14
12/10	.04	5.1	.01	.02	120	.00	.2	.13	.01	.04
12/11	.03	1.1	.03	.04	515	.00	.9	.22	.05	.82
12/14	.11	5.8	.02	.06	5050	.02	6.2	.87	.14	1.07
12/20	.43	11.3	.04	.18	25100	.08	7.8	2.49	.18	.69
12/21	.73	24.1	.03	.16	60400	.19	25.4	3.02	.25	1.05
12/24	.77	30.0	.03	.22	72000	.22	35.8	2.60	.29	1.19
12/25	1.28	18.0	.07	.30	135000	.42	24.1	5.14	.32	1.34
12/26	.34	6.6	.05	.16	43900	.14	12.6	3.30	.40	1.91
12/29	.30	12.0	.03	.06	26500	.08	15.5	1.02	.27	1.29
12/30	.84	23.9	.04	.14	99600	.31	29.8	2.88	.37	1.25
Sum	28.61	969.8	2.71	11.02	2082642	6.41	1,021.3	178.12	15.18	87.18
Average	.35	11.8	.03	.13	25398	.08	12.5	2.17	.19	1.06
Minimum	.03	.7	.01	.02	120	.00	.2	.07	.01	.04
Maximum	1.66	56.5	.10	.50	135000	.42	55.9	7.17	.64	4.93

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Table A-6b. Surrey Downs Runoff Conditions for 1981

Runoff Start Date	Total Rain (Inches)	Rain Duration (hrs)	Average Rain Int. (in/hr)	Peak 30 Min Int. (in/hr)	Total Discharge (cubic feet)	Total Discharge (inches)	Runoff Duration (hrs)	Peak Discharge (cfs)	Runoff Coefficient (Rv-ratio)	Runoff/Rain Duration (ratio)
1/6/81	.05	1.5	.03	.02	1080	.00	1.4	.37	.07	.92
1/8	.04	3.1	.01	.04	1110	.00	1.2	.51	.09	.39
1/17	.11	7.3	.02	.08	4030	.01	6.6	.87	.11	.90
1/18	.11	5.8	.02	.04	6340	.02	6.0	.87	.18	1.04
1/20	.27	9.6	.03	.10	16600	.05	9.8	1.63	.19	1.02
1/21	.42	32.3	.01	.12	35900	.11	33.2	2.27	.26	1.03
1/23	.38	10.6	.04	.14	29700	.09	14.2	2.60	.24	1.35
1/27	.09	4.5	.02	.04	5640	.02	4.2	.80	.19	.93
1/28	.63	15.4	.04	.10	56300	.17	20.7	1.73	.28	1.35
2/11	.91	22.8	.04	.18	63800	.20	26.2	2.74	.22	1.15
2/13	1.05	70.0	.02	.16	141000	.44	72.1	3.30	.41	1.03
2/17	.16	6.4	.03	.06	18000	.06	12.3	1.83	.35	1.92
2/18	.73	25.2	.03	.42	84000	.26	31.3	6.54	.36	1.24
2/24	.36	15.7	.02	.10	34300	.11	22.8	1.63	.29	1.46
3/3	.62	25.8	.02	.10	38300	.12	19.3	2.05	.19	.75
3/5	.10	4.8	.02	.08	8310	.03	4.5	1.94	.26	.95
3/15	.28	25.5	.01	.08	23300	.07	25.8	2.16	.26	1.01
3/21	.04	NA	NA	NA	NA	NA	NA	NA	NA	NA
3/22	.03	NA	NA	NA	NA	NA	NA	NA	NA	NA
3/23	.34	12.1	.03	.14	18800	.06	11.7	1.94	.17	.96
3/24	.26	7.9	.03	.08	14600	.05	7.7	2.16	.17	.98
3/28	.18	12.0	.02	.06	7400	.02	10.3	1.02	.13	.86
3/31	.11	3.4	.03	.04	4200	.01	2.5	.80	.12	.73
4/2	.23	17.7	.01	.12	5700	.02	7.8	2.27	.08	.44
4/5	.16	2.3	.07	.12	5250	.02	2.4	1.26	.10	1.05
4/6	.38	3.2	.12	.32	15700	.05	2.8	3.44	.13	.88
4/7	.22	18.3	.01	.06	4310	.01	18.7	.42	.06	1.02
4/10	.34	26.2	.01	.12	9080	.03	17.8	1.44	.08	.68
4/12	.13	11.8	.01	.10	3680	.01	6.4	1.10	.09	.54
4/20	.08	3.6	.02	.04	1260	.00	2.4	.51	.05	.66
4/22	.11	10.0	.01	.06	2010	.01	3.2	.51	.06	.32
4/23	.08	3.0	.03	.06	1600	.00	1.5	.62	.06	.51
4/27	.15	3.3	.05	.06	5490	.02	3.5	.80	.11	1.05
4/28	.32	9.4	.03	.12	19800	.06	10.0	2.16	.19	1.06
5/3	.21	2.3	.09	.14	9690	.03	3.2	1.94	.14	1.39
5/7	.16	6.2	.03	.14	5550	.02	5.7	1.83	.11	.93
5/7	.33	5.7	.06	.26	19600	.06	4.2	4.40	.18	.74
5/9	.05	4.2	.01	.04	1290	.00	1.2	.51	.08	.29
5/10	.29	6.7	.04	.20	20500	.06	5.6	3.89	.22	.83
5/14	.05	2.0	.03	.06	1240	.00	2.2	.42	.08	1.10
5/18	.15	8.8	.02	.06	5370	.02	4.2	.80	.11	.48
5/19	.22	6.3	.04	.10	11800	.04	5.3	1.53	.17	.84
5/24	.04	5.0	.01	.02	100	.00	.1	.33	.01	.02
5/24	.17	7.7	.02	.10	7330	.02	4.3	1.53	.13	.56
5/25	.14	5.0	.03	.10	7870	.02	4.5	1.53	.17	.90
6/4	.03	.7	.04	NA	378	.00	.5	.29	.04	.72
6/5	.33	6.7	.05	.14	17600	.05	6.9	2.16	.16	1.02
6/8	.31	5.1	.06	.12	17500	.05	5.6	1.83	.17	1.10
6/9	.05	.6	.08	.08	1930	.01	1.1	1.26	.12	1.83
6/10	.03	1.3	.02	.04	640	.00	.6	.33	.07	.46
6/12	.23	2.5	.09	.22	10600	.03	2.8	2.74	.14	1.12
6/12	.33	6.6	.05	.28	16500	.05	7.8	4.06	.15	1.18

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Table A-6b(cont.) Surrey Downs Runoff Conditions for 1981

6/15	.11	6.5	.02	.04	3640	.01	6.0	.74	.10	.93
6/18	.23	17.7	.01	.08	8880	.03	8.2	1.10	.12	.46
6/30	.25	5.7	.04	.24	11500	.04	6.5	3.89	.14	1.14
7/6	.53	9.1	.06	.22	26400	.08	9.8	3.16	.15	1.07
7/10	.16	2.6	.06	.16	6230	.02	2.9	1.63	.12	1.12
7/13	1.17	10.2	.12	.30	69800	.22	10.8	3.44	.18	1.06
8/31	.24	13.3	.02	.08	6340	.02	11.2	1.44	.08	.84
9/1	.06	.4	.15	.12	1300	.00	.9	.87	.07	2.25
9/18	.45	13.2	.03	.26	17500	.05	13.3	3.89	.12	1.00
9/19	.05	1.7	.03	.04	1260	.00	1.3	.56	.08	.75
9/20	.68	30.9	.02	.22	38200	.12	28.9	3.30	.17	.94
9/25	.58	10.5	.06	.28	33900	.10	10.2	3.72	.18	.97
9/26	1.22	39.4	.03	.28	77800	.24	38.1	7.40	.20	.97
9/28	.43	9.1	.05	.40	25300	.08	11.3	4.74	.18	1.24
10/1	.81	9.6	.08	.40	52100	.16	12.8	5.94	.20	1.33
10/5	4.38	33.7	.13	.64	409000	1.26	52.1	12.00	.29	1.55
10/7	.14	5.4	.03	.14	18300	.06	16.4	2.60	.40	3.05
10/8	.24	9.6	.03	.10	19200	.06	11.3	1.94	.25	1.18
10/27	.74	27.4	.03	.14	39500	.12	28.4	2.49	.16	1.04
10/28	.10	1.2	.08	.10	6230	.02	2.7	1.73	.19	2.24
10/29	.07	5.4	.01	.04	2940	.01	2.9	.56	.13	.54
10/30	.09	3.2	.03	.06	4230	.01	4.1	1.02	.15	1.28
11/11	1.50	20.3	.07	.26	98900	.31	27.0	4.06	.20	1.33
11/13	.11	8.5	.01	.08	6030	.02	9.9	1.18	.17	1.17
11/13	.10	2.6	.04	.10	6370	.02	4.8	1.63	.20	1.82
11/17	.51	16.5	.03	.14	37000	.11	20.1	2.38	.22	1.22
11/19	.13	6.5	.02	.08	7090	.02	6.4	1.18	.17	.98
11/20	.07	1.0	.07	.08	3500	.01	2.2	.94	.15	2.20
11/20	.03	1.4	.02	.04	1600	.00	2.4	.37	.16	1.68
11/20	.86	28.7	.03	.26	69900	.22	34.2	3.58	.25	1.19
11/22	.03	1.3	.02	.04	4140	.01	5.4	.46	.43	4.14
11/22	.49	5.5	.09	.22	39500	.12	11.3	3.44	.25	2.05
11/23	.18	4.7	.04	.18	19300	.06	11.6	3.02	.33	2.45
11/30	.14	15.6	.01	.10	7360	.02	10.3	1.44	.16	.66
12/1	.55	18.3	.03	.24	33200	.10	21.7	4.40	.19	1.18
12/3	.03	.8	.04	.04	880	.00	1.2	.33	.09	1.52
12/3	.16	7.0	.02	.12	12600	.04	9.3	1.83	.24	1.34
12/4	1.10	17.7	.06	.28	103000	.32	26.2	5.34	.29	1.48
12/5	.17	9.4	.02	.06	26900	.08	18.6	1.10	.49	1.97
12/6	.05	5.0	.01	.06	8290	.03	11.1	.87	.51	2.22
12/9	.78	31.2	.03	.16	72800	.22	38.8	2.60	.29	1.24
12/13	.36	6.1	.06	.18	22400	.07	7.8	2.88	.19	1.28
12/15	.62	13.2	.05	.28	65500	.20	19.3	5.14	.33	1.46
12/17	.15	5.2	.03	.06	9750	.03	7.5	1.18	.20	1.45
12/18	.14	3.8	.04	.08	12700	.04	8.8	1.18	.28	2.33
12/18	.79	19.3	.04	.14	83100	.26	24.4	3.16	.32	1.27
12/21	.08	.8	.10	.12	3980	.01	1.2	1.83	.15	1.50
12/24	.27	8.7	.03	.12	17100	.05	7.5	2.05	.20	.86
12/24	.09	1.7	.05	.12	7450	.02	4.3	3.89	.26	2.53
12/26	.45	22.5	.02	.34	31400	.10	23.7	3.72	.22	1.05
12/27	.06	1.2	.05	.06	4220	.01	3.3	.94	.22	2.75
12/28	.04	5.0	.01	.04	2460	.01	2.3	.87	.19	.46
Sum	35.36	1,069.1	3.91	13.88	2540048	7.84	1,158.8	220.82	18.81	121.40
Average	.34	10.5	.04	.14	24902	.08	11.4	2.16	.18	1.19
Minimum	.03	.4	.01	.02	100	.00	.1	.29	.01	.02
Maximum	4.38	70.0	.15	.64	409000	1.26	72.1	12.00	.51	4.14

Table A-6c. Surrey Downs Runoff Conditions for 1982

Runoff Start Date	Total Rain (Inches)	Rain Duration (hrs)	Average Rain Int. (in/hr)	Peak 30 Min Int. (in/hr)	Total Discharge (cubic feet)	Total Discharge (inches)	Runoff Duration (hrs)	Peak Discharge (cfs)	Runoff Coefficient (Rv-ratio)	Runoff/Rain Duration (ratio)
1/10/82	.30	25.0	.01	.12	17800	.05	21.2	1.73	.18	.85
1/13	.05	6.3	.01	.02	2700	.01	5.6	.29	.17	.90
1/15	1.10	28.9	.04	.16	90800	.28	34.3	3.02	.25	1.18
1/17	.16	8.9	.02	.10	13800	.04	10.7	1.44	.27	1.20
1/22	1.17	35.5	.03	.22	91000	.28	41.7	3.16	.24	1.18
1/25	.13	5.2	.03	.10	11600	.04	11.2	1.63	.28	2.15
1/25	1.01	17.4	.06	.14	98200	.30	24.3	3.72	.30	1.40
1/27	.07	5.8	.01	.04	11400	.04	11.8	.62	.50	2.02
1/27	.04	3.3	.01	.02	6110	.02	8.6	.33	.47	2.58
1/30	.72	42.4	.02	.34	56800	.18	46.8	4.40	.24	1.11
2/1	.43	25.3	.02	.06	49700	.15	31.2	1.26	.36	1.23
Sum	5.18	204.0	.25	1.32	449910	1.39	247.4	21.60	3.26	15.80
Average	.47	18.5	.02	.12	40901	.13	22.5	1.96	.30	1.44
Minimum	.04	3.3	.01	.02	2700	.01	5.6	.29	.17	.85
Maximum	1.17	42.4	.06	.34	98200	.30	46.8	4.40	.50	2.58

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Table A-7a. Lake Hills Runoff Conditions for 1980

Runoff Start Date	Total Rain (inches)	Rain Duration (hrs)	Average Rain Int. (in/hr)	Peak 30 Min Int. (in/hr)	Total Discharge (cubic feet)	Total Discharge (inches)	Runoff Duration (hours)	Peak Discharge (cfs)	Runoff Coefficient (Rv-ratio)	Runoff/Rain Duration (ratio)
2/15/80	.12	6.0	.02	.02	940	.00	3.2	.16	.02	.53
2/17	.69	31.4	.02	.08	73300	.21	31.1	3.07	.31	.99
2/19	.32	9.7	.03	.14	31700	.09	11.8	3.50	.29	1.22
2/25	1.44	49.7	.03	.12	141000	.41	53.8	3.72	.28	1.08
2/28	.36	12.9	.03	.14	47000	.14	13.8	5.79	.38	1.07
3/3	.19	7.9	.02	.06	9120	.03	5.7	.86	.14	.72
3/10	.76	33.0	.02	.30	69500	.20	24.4	6.97	.26	.74
3/12	1.05	43.8	.02	.14	143000	.41	44.0	5.40	.39	1.01
3/19	.27	16.9	.02	.06	25600	.07	17.3	1.94	.27	1.03
3/26	.21	21.0	.01	.22	15300	.04	4.8	5.53	.21	.23
3/29	.12	6.7	.02	.06	3210	.01	3.8	.92	.08	.57
4/5	.07	2.3	.03	.06	2220	.01	2.0	.61	.09	.86
4/5	.45	18.8	.02	.16	37800	.11	20.1	3.72	.24	1.07
4/8	.92	20.9	.04	.22	91800	.27	23.1	7.72	.29	1.10
4/14	.32	10.7	.03	.18	17300	.05	11.4	2.97	.16	1.07
4/18	1.33	34.1	.04	.20	132000	.38	36.1	4.68	.29	1.06
4/28	.07	2.2	.03	.04	1570	.00	1.6	.53	.06	.73
4/29	.07	.4	.17	.14	1660	.00	1.0	.92	.07	2.40
5/20	.10	9.1	.01	.04	1980	.01	8.5	.18	.06	.94
5/21	.19	4.8	.04	.12	11000	.03	4.9	2.51	.17	1.03
5/22	.06	2.6	.02	.04	835	.00	1.8	.41	.04	.69
5/24	.15	5.4	.03	.08	5850	.02	5.3	1.05	.11	.99
5/25	.07	8.8	.01	.02	1240	.00	6.6	.24	.05	.75
5/26	.50	16.1	.03	.12	38100	.11	15.7	2.60	.22	.97
5/27	.10	6.3	.02	.04	4070	.01	3.9	.61	.12	.62
6/1	.69	7.8	.09	.18	54900	.16	9.3	6.37	.23	1.19
6/1	.06	.9	.07	.10	2690	.01	.6	2.42	.13	.67
6/5	.17	21.3	.01	.02	6920	.02	23.1	.32	.12	1.09
6/8	.17	8.9	.02	.14	9170	.03	4.6	3.17	.16	.51
6/16	.32	2.2	.15	.28	21000	.06	3.2	6.22	.19	1.45
6/23	.04	8.0	.01	.02	2700	.01		.10	.20	.00
6/24	.72	9.9	.07	.22	52400	.15	10.0	6.37	.21	1.01
6/25	.08	.8	.10	.10	3630	.01	1.0	2.87	.13	1.25
7/4	.09	3.5	.03	.04	1570	.00	1.5	.57	.05	.43
7/11	.28	17.5	.02	.08	9870	.03	12.7	1.05	.10	.73
7/14	.15	6.5	.02	.10	6090	.02	7.1	1.94	.12	1.09
8/2	.09	2.0	.05	.04	2770	.01	2.3	.65	.09	1.15
8/17	.63	9.3	.07	.58	54400	.16	8.8	19.50	.25	.95
8/26	.04	.5	.08	.08	1210	.00	1.2	.65	.09	2.40
8/27	.17	1.2	.14	.28	14300	.04	2.3	7.42	.24	1.92
8/28	.26	2.6	.10	.22	15900	.05	3.9	5.40	.18	1.50
8/30	.04	5.0	.01	.04	2100	.01		.10	.15	.00
8/31	.08	13.3	.01	.02	2920	.01	6.3	.80	.11	.47
9/1	.57	17.8	.03	.14	56900	.16	19.0	5.47	.29	1.07
9/6	.23	4.2	.06	.22	14800	.04	3.6	6.07	.19	.86
9/12	.12	4.6	.03	.06	3710	.01	3.0	.92	.09	.65
9/13	.16	11.4	.01	.04	4810	.01	9.1	.41	.09	.80
9/19	.10	3.4	.03	.04	3280	.01	2.4	.57	.09	.70
9/20	.25	13.9	.02	.16	17300	.05	13.7	6.52	.20	.99

Table A-7a. Lake Hills Runoff Conditions for 1980 (cont.)

Runoff Start Date	Total Rain (inches)	Rain Duration (hrs)	Average Rain Int. (in/hr)	Peak 30 Min Int. (in/hr)	Total Discharge (cubic feet)	Total Discharge (inches)	Runoff Duration (hours)	Peak Discharge (cfs)	Runoff Coefficient (Rv-ratio)	Runoff/Rain Duration (ratio)
9/29	.49	5.5	.09	.28	44800	.13	6.1	9.19	.26	1.11
10/8	.11	9.2	.01	.12	2590	.01	6.8	1.51	.07	.74
10/12	.16	16.0	.01	.08	6780	.02	15.0	1.12	.12	.94
10/24	.17	7.4	.02	.10	8140	.02	6.8	1.67	.14	.92
10/31	.74	24.7	.03	.10	58200	.17	23.5	2.69	.23	.95
11/1	.36	10.6	.03	.14	38700	.11	11.9	6.37	.31	1.12
11/3	.52	22.6	.02	.14	47500	.14	17.1	4.56	.26	.76
11/5	.35	3.7	.10	.24	39300	.11	4.3	11.20	.32	1.17
11/6	.77	12.4	.06	.22	106000	.31	14.4	11.40	.40	1.16
11/7	.43	19.5	.02	.20	59800	.17	20.8	6.67	.40	1.06
11/8	.24	8.3	.03	.24	27000	.08	9.8	6.82	.33	1.18
11/9	.17	11.3	.02	.12	15200	.04	12.2	3.07	.26	1.08
11/14	.15	4.8	.03	.08	9710	.03	3.4	1.78	.19	.70
11/17	.03	1.2	.03	.02	730	.00	.8	.41	.07	.67
11/19	.19	2.7	.07	.18	17400	.05	3.4	8.85	.26	1.25
11/20	1.55	23.1	.07	.42	223000	.64	30.3	16.20	.42	1.31
11/23	.06	1.4	.04	.10	4490	.01	1.2	4.56	.22	.86
11/25	.16	2.7	.06	.12	12600	.04	2.7	2.87	.23	1.00
11/27	.70	13.7	.05	.26	86400	.25	17.2	13.20	.36	1.25
11/28	.61	17.9	.03	.18	77600	.22	22.8	6.22	.37	1.27
11/30	.08	2.1	.04	.06	9410	.03	4.0	1.62	.34	1.90
11/30	.14	6.4	.02	.04	16200	.05	8.2	1.22	.33	1.29
12/2	1.02	15.0	.07	.28	158000	.46	19.4	10.60	.45	1.29
12/3	.43	18.7	.02	.18	73200	.21	24.2	5.16	.49	1.29
12/4	.23	4.8	.05	.06	15400	.04	10.8	3.17	.19	2.25
12/10	.06	7.5	.01	.04	2490	.01	6.3	.38	.12	.84
12/14	.17	5.9	.03	.12	14500	.04	6.4	3.07	.25	1.09
12/20	.43	11.3	.04	.14	37200	.11	11.5	3.96	.25	1.02
12/21	.60	15.8	.04	.14	70700	.20	19.6	5.92	.34	1.24
12/22	.08	10.0	.01	.06	1450	.00	2.2	.29	.05	.22
12/24	.73	30.4	.02	.20	84500	.24	33.1	5.92	.33	1.09
12/25	1.28	17.3	.07	.30	210000	.61	23.0	12.80	.47	1.33
12/26	.32	5.9	.05	.16	53000	.15	11.9	7.12	.48	2.01
12/29	.30	11.5	.03	.04	31400	.09	12.8	1.40	.30	1.11
12/30	.83	27.7	.03	.12	129000	.37	33.2	4.92	.45	1.20
sum	30.10	966.8	3.32	11.28	3064825	8.86	961.5	340.40	18.35	86.02
average	.36	11.5	.04	.13	36486	.11	11.7	4.05	.22	1.02
minimum	.03	.4	.01	.02	730	.00	.6	.10	.02	.00
maximum	1.55	49.7	.17	.58	223000	.64	53.8	19.50	.49	2.40

Table A-7b. Lake Hills Runoff Conditions for 1981

Runoff Start Date	Total Rain (inches)	Rain Duration (hrs)	Average Rain Int. (in/hr)	Peak 30 Min Int. (in/hr)	Total Discharge (cubic feet)	Total Discharge (inches)	Runoff Duration (hours)	Peak Discharge (cfs)	Runoff Coefficient (Rv-ratio)	Runoff/Rain Duration (ratio)
1/6/81	.07	1.2	.06	.08	2900	.01	1.6	1.04	.12	1.33
1/8	.03	1.0	.03	.04	310	.00	.5	.24	.03	.50
1/17	.06	4.6	.01	.04	2020	.01	4.7	.45	.10	1.02
1/18	.09	6.9	.01	.04	6440	.02	6.1	.65	.21	.88
1/22	.11	8.5	.01	.04	9400	.03	9.4	.70	.25	1.11
1/23	.48	14.5	.03	.16	53000	.15	14.8	7.87	.32	1.02
1/26	.16	5.3	.03	.06	11000	.03	5.1	1.34	.20	.96
1/27	.06	2.2	.03	.02	3250	.01	2.7	.75	.16	1.22
1/28	.60	17.1	.04	.08	75000	.22	18.1	2.26	.36	1.06
2/11	1.00	22.7	.04	.20	90200	.26	26.2	5.28	.26	1.15
2/13	.24	9.6	.03	.08	19900	.06	10.3	1.94	.24	1.07
2/13	.53	37.9	.01	.14	58400	.17	41.0	4.08	.32	1.08
2/15	.47	22.4	.02	.20	51000	.15	26.0	7.87	.31	1.16
2/17	.16	8.0	.02	.06	10600	.03	7.6	1.86	.19	.95
2/18	.58	18.7	.03	.36	46300	.13	19.8	9.19	.23	1.06
3/24	.21	6.4	.03	.08	13000	.04	7.3	1.78	.18	1.15
3/29	.14	9.3	.02	.06	4700	.01	3.6	.75	.10	.39
3/31	.32	11.9	.03	.08	22300	.06	12.8	1.62	.20	1.08
4/2	.07	3.3	.02	.06	1940	.01	2.8	.61	.08	.84
4/2	.20	6.9	.03	.22	14300	.04	6.3	6.37	.21	.91
4/4	.06	1.7	.04	.04	2770	.01	3.0	.53	.13	1.75
4/5	.18	3.8	.05	.12	12500	.04	3.8	3.17	.20	.99
4/5	.04	.9	.04	.04	2180	.01	1.8	1.16	.16	1.98
4/6	.34	1.9	.18	.28	36900	.11	3.8	7.12	.31	2.01
4/7	.28	20.0	.01	.06	16300	.05	21.1	.80	.17	1.06
4/10	.42	32.3	.01	.14	31400	.09	31.1	3.72	.22	.96
4/12	.12	6.7	.02	.08	7340	.02	7.5	2.02	.18	1.13
4/20	.19	3.1	.06	.14	8350	.02	3.1	2.18	.13	1.00
4/21	.27	16.9	.02	.08	17600	.05	10.7	2.02	.19	.63
4/23	.08	2.4	.03	.06	2880	.01	2.2	1.04	.10	.91
4/27	.18	4.7	.04	.06	6960	.02	4.5	.80	.11	.95
4/28	.35	14.0	.03	.12	23300	.07	9.9	2.78	.19	.71
5/3	.29	4.4	.07	.22	13900	.04	5.1	2.78	.14	1.16
5/7	.33	16.5	.02	.16	17700	.05	13.8	4.08	.16	.84
5/11	.39	6.1	.06	.26	24700	.07	4.7	5.66	.16	.77
5/14	.18	4.2	.04	.22	12500	.04	1.5	7.57	.20	.36
5/14	.08	.3	.32	.16	4680	.01	.9	5.53	.17	3.60
5/18	.20	7.1	.03	.12	9530	.03	3.8	2.34	.14	.53
5/19	.24	5.5	.04	.10	14100	.04	5.5	2.10	.17	1.01
5/24	.03	.8	.04	.04	530	.00	.8	.24	.05	1.00
5/24	.36	14.4	.03	.20	20500	.06	14.4	5.40	.16	1.00
6/3	.06	4.3	.01	.04	1210	.00	1.5	.92	.06	.35
6/4	.03	.8	.04	.04	260	.00	.4	.22	.03	.53
6/5	.43	6.2	.07	.16	27700	.08	6.7	3.84	.19	1.08
6/7	.07	4.7	.02	.08	2050	.01	1.2	1.40	.08	.26
6/8	.40	5.7	.07	.16	29100	.08	5.2	3.61	.21	.91
6/9	.08	4.0	.02	.06	4190	.01	4.1	3.28	.15	1.03
6/12	.28	4.2	.07	.18	16200	.05	3.6	3.84	.17	.86
6/12	.21	6.8	.03	.12	11000	.03	6.9	2.97	.15	1.02
6/15	.10	5.6	.02	.08	2540	.01	5.8	.70	.07	1.04
6/17	.37	21.8	.02	.08	12500	.04	20.7	1.34	.10	.95
6/19	.02	.1	.20	.04	212	.00	.3	.22	.03	3.30

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Table A-7h(cont.) Lake Hills Runoff Conditions for 1981

6/21	.04	2.7	.02	.06	90	.00	NA	.12	.01	NA
6/30	.33	6.5	.05	.28	21900	.06	7.0	10.80	.19	1.08
7/6	.64	8.8	.07	.20	48800	.14	9.7	6.97	.22	1.11
7/10	.04	1.7	.02	.06	588	.00	.6	.45	.04	.36
7/13	1.25	10.1	.12	.34	126000	.36	11.5	9.19	.29	1.14
8/31	.18	12.0	.02	.04	3860	.01	10.8	.32	.06	.90
9/1	.12	1.0	.12	.18	3870	.01	1.2	2.34	.09	1.20
9/18	.45	12.9	.04	.26	19200	.06	NA	6.70	.12	NA
9/19	.10	1.8	.06	.14	7380	.02	1.9	7.12	.21	1.06
9/20	1.05	31.8	.03	.26	87100	.25	28.7	13.40	.24	.90
9/25	1.06	9.1	.12	.64	118000	.34	14.8	20.00	.32	1.62
9/26	.14	14.0	.01	.04	5510	.02	13.0	.98	.11	.93
9/27	1.20	8.0	.15	.50	121000	.35	15.6	15.00	.29	1.95
9/28	.14	4.2	.03	.08	13400	.04	7.2	2.51	.28	1.70
9/28	.42	11.7	.04	.24	41000	.12	15.2	6.82	.28	1.30
10/1	.76	8.5	.09	.36	84600	.24	14.7	15.60	.32	1.72
10/5	3.69	35.8	.10	.52	490000	1.42	28.1	19.00	.38	.78
10/8	.27	9.6	.03	.16	42600	.12	19.2	5.40	.46	1.99
10/27	.73	27.0	.03	.14	52000	.15	28.4	4.08	.21	1.05
10/28	.11	1.3	.09	.10	8510	.02	2.2	2.51	.22	1.70
10/29	.16	10.7	.02	.10	10200	.03	11.1	2.69	.18	1.04
10/30	.07	2.8	.03	.06	3060	.01	3.5	.80	.13	1.25
11/3	.10	6.3	.02	.08	4380	.01	6.1	2.10	.13	.98
11/11	1.58	20.8	.08	.38	189000	.55	30.7	13.20	.35	1.48
11/13	.14	8.8	.02	.10	11400	.03	10.0	2.78	.24	1.14
11/14	.05	.5	.10	.10	3930	.01	1.5	2.60	.23	3.00
11/14	.31	15.5	.02	.10	28800	.08	16.4	3.50	.27	1.06
11/15	.14	2.3	.06	.14	13100	.04	5.2	3.50	.27	2.27
11/17	.53	18.3	.03	.16	60900	.18	21.4	4.08	.33	1.17
11/19	.18	18.0	.01	.06	13300	.04	17.6	1.16	.21	.98
11/20	.03	1.8	.02	.02	760	.00	1.5	.18	.07	.85
11/20	.88	30.3	.03	.20	122000	.35	42.0	7.27	.40	1.38
11/22	.35	5.3	.07	.14	47400	.14	11.2	5.40	.39	2.11
11/23	.21	4.8	.04	.22	29600	.09	10.8	9.53	.41	2.26
11/30	.09	10.0	.01	.04	2170	.01	4.3	.65	.07	.43
12/1	.03	1.2	.03	.04	1440	.00	1.0	.80	.14	.83
12/1	.57	18.4	.03	.30	62900	.18	23.2	11.60	.32	1.26
12/3	.16	14.5	.01	.08	12400	.04	14.3	2.69	.22	.98
12/4	1.21	21.6	.06	.38	174000	.50	23.0	13.40	.42	1.06
12/5	.22	15.7	.01	.06	34700	.10	NA	2.26	.46	NA
12/8	.03	.7	.04	.04	1190	.00	.9	.70	.11	1.29
12/9	.84	30.0	.03	.20	116000	.34	36.0	6.07	.40	1.20
12/13	.30	8.8	.03	.16	29700	.09	10.1	4.08	.29	1.14
12/14	.96	23.4	.04	.32	137000	.40	28.8	10.40	.41	1.23
12/17	.21	15.0	.01	.06	21800	.06	18.6	1.16	.30	1.24
12/18	.69	19.2	.04	.20	111000	.32	24.9	7.57	.47	1.30
12/21	.09	1.2	.08	.10	8670	.03	6.4	2.78	.28	5.33
12/24	.26	10.8	.02	.10	23400	.07	8.8	2.97	.26	.81
12/24	.07	1.7	.04	.12	7810	.02	4.8	3.61	.32	2.81
12/26	.40	23.5	.02	.26	43400	.13	18.1	6.97	.31	.77
12/27	.07	7.0	.01	.08	5330	.02	7.3	.70	.22	1.04
12/28	.10	8.3	.01	.04	9160	.03	7.6	2.02	.26	.91
12/30	.06	2.4	.03	.08	1080	.00	2.4	.20	.05	1.00
sum	36.05	1,048.2	4.56	14.96	3525930	10.19	1,095.4	430.76	22.01	123.71
average	.34	10.0	.04	.14	33580	.10	10.7	4.10	.21	1.21
minimum	.02	.1	.01	.02	90	.00	.3	.12	.01	.26
maximum	3.69	37.9	.32	.64	490000	1.42	42.0	20.00	.47	5.33

Table A-7c. Lake Hills Runoff Conditions for 1982

Runoff Start Date	Total Rain (inches)	Rain Duration (hrs)	Average Rain Int. (in/hr)	Peak 30 Min Int. (in/hr)	Total Discharge (cubic feet)	Total Discharge (inches)	Runoff Duration (hours)	Peak Discharge (cfs)	Runoff Coefficient (Rv-ratio)	Runoff/Rain Duration Ratio
1/10/82	.35	25.0	.01	.12	25500	.07	21.7	2.69	.21	.87
1/15	.98	28.0	.04	.14	106000	.31	33.2	4.08	.31	1.19
1/17	.18	12.9	.01	.10	20600	.06	11.8	2.87	.33	.92
1/22	.58	13.5	.04	.12	64300	.19	19.0	4.20	.32	1.41
1/23	.74	10.1	.07	.18	120000	.35	16.1	6.97	.47	1.59
1/25	.12	5.2	.02	.08	14400	.04	10.9	2.78	.35	2.09
1/25	.96	17.8	.05	.12	162000	.47	23.7	5.53	.49	1.33
1/27	.06	2.9	.02	.04	10900	.03	8.9	1.10	.53	3.12
1/27	.04	4.0	.01	.02	7040	.02	9.7	.41	.51	2.43
1/30	.06	6.0	.01	.06	3490	.01	5.5	.57	.17	.92
1/30	.14	5.6	.03	.12	16200	.05	7.9	4.32	.33	1.41
2/1	.73	40.6	.02	.06	93800	.27	44.4	1.86	.37	1.09
sum	4.94	171.5	.34	1.16	644230	1.86	212.8	37.38	4.39	18.35
average	.41	14.3	.03	.10	53686	.16	17.7	3.12	.37	1.53
minimum	.04	2.9	.01	.02	3490	.01	5.5	.41	.17	.87
maximum	.98	40.6	.07	.18	162000	.47	44.4	6.97	.53	3.12

Table A-8. Lake Hills Dry Weather Without Street Cleaning (LHD)

Storm number	Month	Flow (cu ft)	Rain (in)	Runoff Concentrations (mg/1) Total Sol.	TKN	COD	Total Phos.	Lead	Zinc	pH	Spec. Cond. (umhos)	Turb. (ntu)
6	4/14/80	8650	.15	87	2.10	67	.27	.53	.12	NA	NA	NA
8	4/18	132000	1.33	81	.53	13	.19	.10	.08	NA	NA	NA
9	5/21	11000	.19	119	1.51	48	.37	.38	.14	6.3	NA	20
10	5/24	5850	.15	87	.77	16	.02	.15	.11	6.5	49	8
11	5/27	4070	.10	92	.25	31	.12	.12	.07	6.0	26	13
15	6/5	6920	.18	59	.66	26	.10	.12	.10	NA	NA	NA
16	6/8	9170	.17	195	1.46	87	.49	.56	.17	5.7	22	35
18	6/24	52400	.72	95	1.40	41	.28	.19	.10	5.8	42	19
19	6/25	3630	.08	114	1.06	57	.26	.38	.14	6.2	26	15
21	7/11	9870	.28	85	.87	49	.26	.23	.11	5.9	51	9
22	7/14	6090	.15	137	.84	43	.17	.20	.10	5.7	32	7
25	8/26	1210	.04	84	3.58	85	.57	.39	.29	5.3	142	26
26	8/27	30200	.43	190	1.68	75	3.61	.53	.21	6.4	31	29
28+29	9/1	56900	.57	54	.25	30	.08	.05	.08	6.2	22	11
30	9/6	14800	.23	60	.98	47	.27	.26	.13	6.0	24	16
31	9/12	3710	.12	24	.67	32	.15	.05	.11	6.1	34	9
32	9/13	4810	.16	156	.56	39	.10	.05	.12	6.2	54	9
114	7/6/81	48800	.64	89	1.04	52	.34	.10	.11	6.3	36	8
116	7/13	126000	1.25	79	1.23	37	.27	.10	.13	6.3	37	9
117	8/31	19500	.12	114	5.94	100	.19	.20	.19	6.3	46	6
118	9/1	3870	.12	177	2.46	95	.50	.40	.24	6.4	45	16
119	9/19	7380	.10	274	2.58	118	.71	.40	.21	6.1	43	28
120	9/20	87100	1.05	122	1.26	54	.24	.20	.11	6.6	37	12
Total		653930	8.33	2574	33.68	1241	9.55	5.69	3.17	122.3	799	305
Average		28432	.36	112	1.46	54	.42	.25	.14	6.1	42	15
Minimum		1210	.04	24	.25	13	.02	.05	.07	5.3	22	6
Maximum		132000	1.33	274	5.94	118	3.61	.56	.29	6.6	142	35

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Table A-9. Lake Hills Dry Weather With Street Cleaning (CLHD)

Storm number	Date	Flow (cu ft)	Rain (in)	Runoff Concentrations (mg/l) Total Sol.	TKN	COD	Total Phos.	Lead	Zinc	pH	Spec. Cond. (umhos)	Turb. (ntu)
34	9/20/80	17300	.25	199	1.71	20	.34	.39	.17	5.9	26	30
85	3/24/81	13000	.21	71	.93	32	.16	.10	.09	6.2	28	20
86	3/28	4700	.14	66	.73	39	.12	.10	.10	6.5	28	6
89	4/5	12500	.18	87	.73	42	.28	.10	.10	5.9	23	39
90	4/6	36900	.34	135	1.15	42	.49	.20	.13	5.5	25	39
91	4/7	16300	.28	42	.25	27	.15	.05	.08	6.0	40	10
92	4/10	26000	.36	117	.59	32	.23	.10	.09	7.0	23	31
93	4/12	7340	.12	157	.92	29	.51	.10	.12	6.3	35	67
94	4/20	8350	.19	78	1.04	50	.21	.20	.10	6.2	40	12
95	4/21	17600	.27	76	.53	36	.16	.10	.06	5.2	24	20
96	4/23	2880	.08	43	.70	38	.12	.10	.09	5.9	40	10
97	4/27	30300	.53	80	1.18	35	.25	.20	.07	5.4	29	23
101	5/11	25400	.43	239	.90	67	.26	.10	.12	6.4	24	32
102	5/14	12500	.18	161	1.46	62	.22	.30	.18	6.5	35	27
103	5/14	4680	.08	194	1.60	70	.37	.30	.14	6.4	29	46
104	5/18	23700	.44	59	.62	27	.13	.10	.11	5.9	27	17
105	5/24	20500	.36	97	.64	49	.19	.20	.12	NA	NA	8
106	6/5	27700	.43	117	1.96	45	.54	.20	.13	6.1	36	8
107	6/8	29100	.40	73	1.01	36	.25	.10	.09	6.1	17	21
108	6/9	4190	.08	184	1.74	20	.10	.10	.15	6.4	32	35
109	6/12	16200	.28	103	.90	34	.28	.20	.11	5.8	19	22
110	6/12	11000	.21	108	1.04	76	.18	.20	.10	6.1	24	19
112	6/17	12500	.37	27	.50	22	.11	.10	.07	6.5	23	8
113	6/30	21900	.33	206	4.00	122	1.18	.50	.26	5.4	61	27
Total		402540	6.54	2719	26.83	1053	6.84	4.14	2.77	139.6	688	577
Average		16773	.27	113	1.12	44	.28	.17	.12	6.1	30	24
Minimum		2880	.08	27	.25	20	.10	.05	.06	5.7	17	6
Maximum		36900	.53	239	4.00	122	1.18	.50	.26	7.0	61	67

Table A-10. Lake Hills Wet Weather Without Street Cleaning (LHW)

Storm number	Month	Flow (cu ft)	Rain (in)	Runoff Concentrations (mg/l) Total Sol.	TKN	COD	Total Phos.	Lead	Zinc	pH	Spec. Cond. (umhos)	Turb. (ntu)
50	11/27/80	86400	.70	83	.90	28	.15	.10	.16	5.9	27	18
51	11/28	103200	.83	66	.25	23	.13	.05	.07	5.9	29	15
54	12/4	13900	.23	62	.78	27	.12	.10	.08	5.7	50	12
55	12/14	14500	.17	152	.70	77	.31	.30	.22	6.1	29	53
56	12/20	37200	.43	109	.70	36	.24	.20	.10	5.5	23	48
57	12/21	70700	.60	113	.76	33	.21	.10	.14	5.6	27	34
58	12/24	23700	.26	120	1.12	45	.22	.20	.14	5.9	26	33
59	12/24	57500	.44	93	.70	55	.14	.10	.11	7.1	31	14
61	12/26	53000	.32	68	.59	23	.12	.10	.13	7.0	44	8
62	12/29	158000	1.11	60	.53	22	.10	.10	.15	6.0	36	10
127	10/8/81	42600	.27	81	.25	29	.10	.10	.05	7.1	53	8
129	10/28	12500	.20	47	.61	23	.13	.05	.08	NA	NA	7
130	10/29	5640	.07	64	.78	29	.18	.20	.08	6.7	22	9
131	10/30	3060	.07	88	.90	36	.15	.05	.13	7.0	32	14
132	11/11	189000	1.58	53	.73	33	.21	.10	.07	6.6	30	12
133	11/13	11400	.14	50	.64	41	.16	.10	.09	7.1	42	13
134	11/17	60900	.53	33	.28	22	.12	.10	.08	6.8	34	7
135+136	11/20	199000	1.44	46	.38	30	.12	.05	.07	6.9	49	6
137	11/30	3610	.12	34	.50	29	.12	.05	.15	7.0	45	9
140	12/3	12400	.16	119	1.32	38	.12	.10	.08	6.9	85	13
141	12/4	209000	1.43	108	.92	30	.13	.10	.05	6.7	46	6
148	12/9	111000	.84	95	.42	20	.09	.05	.03	6.8	42	6
149	12/13	29700	.30	61	.25	26	.15	.10	.07	6.7	25	10
150	12/14	132000	.96	62	.50	21	.11	.10	.05	6.8	48	7
151	12/17	21800	.21	45	.31	17	.07	.10	.06	6.9	55	7
152	12/18	111000	.69	51	.48	19	.08	.10	.09	6.7	35	7
153	12/21	8670	.09	51	.48	24	.08	.10	.08	6.8	34	9
154	12/23	23400	.26	33	.31	20	.07	.05	.04	6.9	23	8
155	12/28	9160	.10	58	1.37	39	.12	.05	.08	7.1	70	12
156	1/10/82	25500	.35	227	1.37	77	.34	.40	.15	6.7	69	82
158	1/15	106000	.98	78	.48	25	.11	.10	.08	6.8	31	14
159	1/17	20600	.18	82	.67	33	.12	.10	.06	7.0	43	15
Total		1966040	16.06	2492	20.98	1031	4.62	3.60	3.00	204.7	1235	526
Average		61439	.50	78	.66	32	.14	.11	.09	6.6	40	16
Minimum		3060	.07	33	.25	17	.07	.05	.03	5.5	22	6
Maximum		209000	1.58	227	1.37	77	.34	.40	.22	7.1	85	82

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Table A-11. Lake Hills Wet Weather With Street Cleaning (CLHW)

				Runoff Concentrations (mg/l)								
Storm number	Date	Flow (cu ft)	Rain (in)	Total Sol.	TKN	COD	Total Phos.	Lead	Zinc	pH	Spec. Cond. (umhos)	Turb. (ntu)
37	10/8/80	2590	.11	168	3.80	78	.26	.28	.16	6.6	55	24
38	10/12	6780	.16	27	.79	22	.20	.10	.08	5.5	34	17
39	10/24	8140	.17	138	1.12	80	.38	.29	.18	5.9	43	22
40+41	10/31	58200	.74	106	.96	41	.21	.18	.13	6.1	25	41
42	11/1	38700	.36	188	1.46	63	.30	.31	.12	5.6	22	52
43	11/3	47500	.52	85	.62	35	.16	.10	.23	6.4	24	26
45	11/8	42200	.41	68	.67	36	.14	.10	.07	5.6	30	17
46	11/14	9710	.15	125	.73	83	.17	.15	.11	5.9	31	23
47	11/19	17400	.19	442	1.88	38	.92	.25	.16	5.6	19	145
48	11/20	223000	1.55	92	1.04	32	.29	.10	.09	5.7	26	38
49	11/23	17100	.22	72	.95	22	.52	.15	.11	5.6	31	32
63	1/17/81	8460	.15	142	.70	45	.51	.20	.16	6.8	40	72
66	1/23	53000	.48	161	.95	57	.28	.30	.10	6.3	22	32
67	1/26	11000	.16	81	.25	24	.27	.05	.07	6.2	40	18
69	1/28	75000	.60	69	.25	13	.03	.10	.05	6.0	26	18
70+71	2/11	90200	1.00	90	.64	43	.22	.14	.07	6.4	24	33
72	2/13	19900	.24	66	.25	27	.13	.10	.06	5.9	26	25
73+74	2/13	113200	1.01	218	1.26	33	.45	.30	.12	5.7	36	50
76	2/17	10600	.16	74	.73	31	.15	.15	.07	6.0	37	18
77+78	2/18	51080	.58	NA	1.40	56	.34	.29	.12	6.1	30	54
Total		903760	8.96	2412	20.45	860	5.93	3.64	2.25	119.9	621	757
Average		45188	.45	127	1.02	43	.30	.18	.11	6.0	31	38
Minimum		2590	.11	27	.25	13	.03	.05	.05	5.5	19	17
Maximum		223000	1.55	442	3.80	83	.92	.31	.23	6.8	55	145

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Table A-12. Surrey Downs Dry Weather Without Street Cleaning (SDD)

Storm number	Date	Flow (cu ft)	Rain (in)	Runoff Concentrations (mg/l) Total Sol.	TKN	COD	Total Phos.	Lead	Zinc	pH	Spec. Cond. (umhos)	Turb. (ntu)
1	3/12/80	108000	1.23	70	.56	23	.13	.10	.08	NA	NA	NA
2	3/26	8550	.19	230	1.26	79	.33	.35	.22	NA	NA	NA
21	7/11	10700	.22	142	1.29	69	.29	.21	.16	6.0	59	12
22	7/14	6150	.15	127	.25	37	.15	.10	.12	6.0	38	7
23	8/17	31800	.63	624	2.91	152	.84	.82	.37	6.2	50	41
25	8/26	2670	.08	106	3.42	128	.95	.51	.30	7.4	95	27
26	8/27	8450	.18	266	1.90	102	1.17	.49	.22	6.5	32	35
27	8/28	23600	.37	144	.84	35	.09	.20	.11	6.6	32	10
28	9/1	31400	.50	58	.68	29	.12	.05	.08	6.3	30	7
30	9/6	11900	.27	90	1.23	47	.31	.22	.29	6.0	26	14
31	9/12	1970	.08	72	.25	24	.11	.05	.09	6.8	42	8
32	9/13	5020	.14	90	1.02	43	.12	.05	.15	6.6	69	7
33	9/19	2870	.09	82	.90	56	.21	.10	.10	6.5	54	12
34	9/20	20300	.38	168	1.43	76	.36	.24	.16	5.3	28	18
35	9/29	23700	.43	115	.92	42	.18	.13	.11	6.1	23	13
81	3/3/81	38300	.62	64	.57	27	.14	.10	.08	5.8	31	14
82	3/5	8310	.10	83	.84	33	.16	.10	.09	5.5	42	14
83	3/15	23300	.28	92	1.06	82	.22	.10	.12	6.2	34	18
84	3/23	18800	.34	82	.78	34	.16	.10	.09	6.1	28	12
85	3/24	14600	.26	76	.67	72	.22	.10	.10	6.2	33	14
86	3/28	7400	.18	62	.25	33	.12	.05	.09	6.5	33	6
88	4/2	5700	.23	191	1.71	100	.51	.20	.15	6.6	30	31
89	4/5	5250	.16	58	1.01	45	.17	.10	.10	6.2	28	16
90	4/6	15700	.38	147	1.15	45	.55	.20	.14	5.5	30	17
91	4/7	4310	.22	49	.25	21	.07	.05	.08	5.9	56	5
92	4/10	8070	.30	67	.70	27	.20	.10	.07	6.1	25	14
93	4/12	3680	.13	117	1.06	46	.26	.20	.10	6.1	38	19
94	4/20	1260	.08	NA	NA	NA	NA	NA	NA	5.9	69	8
95	4/22	2010	.11	128	.78	46	.15	.10	.08	5.3	NA	10
97	4/27	25300	.47	72	.81	33	.19	.20	.08	5.2	26	12
98	5/3	9690	.21	104	1.46	95	.29	.10	.15	6.3	39	19
99	5/7	5550	.16	136	1.46	82	.31	.20	.17	6.1	35	26
100	5/7	19600	.33	188	1.54	61	.36	.20	.13	5.9	25	27
101	5/10	20500	.29	87	.84	40	.20	.10	.09	6.1	25	20
104	5/19	11800	.22	69	.90	79	.19	.10	.11	6.1	31	17
105	5/24	16500	.31	75	.76	45	.20	.10	.12	NA	NA	9
106	6/5	17300	.33	140	1.57	66	.30	.20	.17	6.1	38	6
107	6/8	17500	.31	87	.76	52	.20	.10	.10	5.8	16	18
108	6/9	2160	.05	NA	NA	NA	NA	NA	NA	6.5	46	24
109	6/12	10600	.23	131	1.01	51	.27	.10	.12	6.3	23	20
110	6/12	17100	.33	285	2.10	98	.61	.40	.23	6.6	30	36
112	6/17	8880	.23	31	.67	30	.17	.10	.09	6.5	25	11
113	6/30	11500	.25	324	4.26	149	1.19	.40	.26	5.2	60	28
114	7/6	26400	.53	113	1.15	59	.24	.10	.14	6.2	32	12
115	7/10	6230	.16	149	1.76	103	.28	.20	.17	6.3	38	20
116	7/13	69800	1.17	78	.84	32	.17	.10	.12	6.4	30	6
117	8/31	6340	.24	198	3.10	82	.68	.20	.26	6.5	69	22
119	9/18	18800	.50	336	3.92	131	.89	.50	.28	5.9	47	31
120	9/20	38200	.68	136	1.29	58	.20	.20	.15	6.4	42	8
121	9/25	33900	.58	116	1.06	57	.22	.10	.15	6.2	29	4
122	9/26	103000	1.65	158	1.18	50	.32	.20	.12	6.8	27	11
Total		950420	17.56	6613	62.13	3006	15.76	9.02	7.04	295.6	1788	796
Average		18636	.34	135	1.27	61	.32	.18	.14	6.2	38	16
Minimum		1260	.05	31	<.5	21	.07	<.1	.07	5.2	16	4
Maximum		108000	1.65	624	4.26	152	1.19	.82	.37	7.4	95	41

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Table A-13. Surrey Downs Dry Weather With Street Cleaning (CSDD)

Storm number	Date	Flow (cu ft)	Rain (in)	Runoff Concentrations (mg/l) Total Solids	TKN	COD	Total Phos.	Lead	Zinc
3	4/5/80	22600	.43	112	1.06	50	.25	.27	.13
4+5	4/8	48900	.79	132	.60	39	.24	.20	.11
7	4/14	8590	.18	196	2.74	54	.59	.33	.20
8	4/18	78800	1.18	43	.50	15	.10	.05	.09
Total		158890	2.58	483	4.90	158	1.18	.85	.53
Average		39723	.65	121	1.23	40	.29	.21	.13
Minimum		8590	.18	43	.50	15	.10	.05	.09
Maximum		78800	1.18	196	2.74	54	.59	.33	.20

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Table A-14. Surrey Downs Wet Weather Without Street Cleaning (SDW)

Storm number	Date	Flow (cu ft)	Rain (in)	Runoff Concentrations (mg/1) Total Solids	TKN	COD	Total Phos.	Lead	Zinc	pH	Spec. Cond. (umhos)	Turb.
37	10/8/80	10200	.19	174	1.96	39	.36	.25	.18	NA	48	30
38	10/12	4280	.12	52	NA	26	.17	.07	.08	6.1	61	7
39	10/24	7760	.16	140	1.06	102	.24	.15	.15	6.5	44	22
40	10/31	48500	.74	57	.64	51	.15	.09	.10	6.5	29	12
42	11/1	20700	.29	100	1.09	46	.18	.14	.10	5.7	26	12
43	11/3	41600	.60	95	.78	32	.16	.06	.07	6.3	27	10
44	11/6	87500	1.18	93	.62	51	.08	.10	.18	NA	47	13
45	11/8	36000	.43	64	.62	35	.14	.10	.13	6.2	37	13
46	11/14	5330	.12	250	1.40	50	.23	.20	.31	6.0	46	18
47	11/19	14200	.21	73	1.23	41	.17	.10	.12	5.9	26	16
48	11/20	134000	1.66	60	1.12	30	.15	.10	.17	5.8	30	16
49	11/25	8730	.15	29	.87	31	.26	.10	.11	5.9	28	13
50	11/27	55100	.71	49	.56	29	.11	.05	.08	5.8	31	7
51	11/28	87900	.86	53	1.26	34	.10	.10	.08	6.6	46	7
52	12/2	88000	.97	68	.73	42	.17	.10	.15	6.2	45	13
53	12/3	51200	.46	71	.25	26	.08	.10	.08	6.8	50	6
55	12/14	5050	.11	100	.87	69	.24	.20	.14	6.2	41	23
56	12/20	25100	.43	95	.70	58	.18	.10	.12	6.4	23	21
58	12/24	16600	.26	98	.88	62	.16	.10	.21	5.9	37	20
59	12/24	50500	.51	60	.25	20	.09	.20	.09	7.0	43	6
60	12/25	135000	1.28	76	.70	27	.13	.05	.11	7.0	52	5
61	12/26	49900	.34	83	.64	20	.21	.05	.23	7.0	62	5
62	12/29	127000	1.14	91	.56	19	.09	.05	.09	NA	59	9
63	1/17/81	10400	.22	125	1.01	47	.37	.20	.15	6.4	57	25
64	1/20	16600	.27	98	.25	52	.07	.10	.10	6.4	27	23
65	1/21	35900	.42	91	.78	48	.02	.10	.07	6.1	33	17
69	1/28	59100	.63	68	.25	20	.00	.10	.05	6.0	32	10
70	2/11	63800	.91	80	.64	52	.16	.10	.10	6.1	29	17
72 to 78	2/13	249600	2.20	125	.98	47	.20	.16	.09	6.1	64	15
79	2/24	34300	.36	75	.64	38	.17	.10	.09	6.2	41	17
155	12/28	2460	.04	46	NA	NA	NA	NA	NA	7.0	52	10
156	1/10/82	17800	.30	274	1.93	110	.38	.40	.20	6.7	102	67
158	1/15	90800	1.10	102	.73	38	.17	.10	.10	6.8	111	19
159	1/17	13800	.16	127	.74	33	.09	.10	.08	6.9	73	7
Total		1704710	19.53	3242	26.74	1425	5.49	4.02	4.08	196.5	1559	531
Average		50139	.57	95	.84	43	.17	.12	.12	6.3	46	16
Minimum		2460	.04	29	<.5	19	.00	<.1	.05	5.7	23	5
Maximum		249600	2.20	274	1.96	110	.38	.40	.31	7.0	111	67

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Table A-15. Surrey Downs Wet Weather With Street Cleaning (CSDW)

				Runoff Concentrations (mg/l)								
Storm number	Date	Flow (cu ft)	Rain (in)	Total Solids	TKN	COD	Total Phos.	Lead	Zinc	pH	Spec. Cond. (umhos)	Turb. (ntu)
123	10/1/81	52100	.81	95	.73	28	.15	.10	.08	6.5	30	11
124+125	10/5	401000	4.38	144	1.02	34	.23	.17	.10	6.3	48	9
126	10/7	18300	.14	116	.90	24	.08	.10	.07	7.3	105	5
127	10/8	19200	.24	88	.56	30	.10	.10	.07	7.0	51	10
128	10/27	39500	.74	72	.61	36	.16	.05	.09	6.7	29	12
129	10/28	9170	.17	75	.62	29	.15	.10	.13	6.9	29	15
131	10/30	4230	.09	98	1.80	27	.28	.05	.15	7.3	45	24
132	11/11	98900	1.50	76	.64	33	.17	.10	.08	6.6	30	10
133	11/13	6030	.11	69	.76	44	.16	.10	.16	7.2	56	15
137	11/30	7360	.14	110	1.32	69	.27	.20	.14	7.0	41	23
138+139	12/1	37130	.55	83	.76	36	.18	.19	.12	6.6	40	12
140	12/3	13500	.19	140	.66	48	.13	.10	.10	6.8	87	14
141	12/4	116000	1.27	110	.64	17	.12	.10	.08	NA	NA	NA
148	12/9	72800	.78	114	.48	28	.09	.05	.06	6.9	54	11
149	12/13	22400	.36	79	.62	35	.14	.10	.10	6.8	30	16
150	12/14	81100	.87	97	.62	35	.15	.10	.08	6.8	44	15
151	12/17	22400	.29	133	.59	27	.13	.10	.11	7.0	85	30
152	12/19	83100	.79	64	.48	21	.08	.10	.08	6.9	48	9
153	12/21	3980	.08	194	.95	53	.20	.20	.14	7.0	62	42
154	12/23	17100	.27	73	.56	33	.12	.05	.07	6.9	295	18
Total		1125300	13.77	2030	15.32	687	3.08	2.16	2.00	130.5	1209	301
Average		56265	.69	102	.77	34	.15	.11	.10	6.9	64	16
Minimum		3980	.08	64	.48	17	.08	.05	.06	6.3	29	5
Maximum		401000	4.38	194	1.80	69	.28	.20	.16	7.3	295	42

Table A-16. Lake Hills Dry Weather Without Street Cleaning (LHD)

Storm number	Month	Flow (cu ft)	Rain (in)	Total Solids	Runoff Yields (lb/acre/storm) TKN	COD	Total Phos.	Lead	Zinc
6	4/14/80	8650	.15	.46	.011	.35	.0014	.0028	.0006
8	4/18	132000	1.33	6.55	.043	1.03	.0154	.0081	.0066
9	5/21	11000	.19	.80	.010	.32	.0025	.0026	.0009
10	5/24	5850	.15	.31	.003	.06	.0001	.0005	.0004
11	5/27	4070	.10	.23	.001	.08	.0003	.0003	.0002
15	6/5	6920	.18	.25	.003	.11	.0004	.0005	.0004
16	6/8	9170	.17	1.10	.008	.49	.0028	.0031	.0010
18	6/24	52400	.72	3.05	.045	1.32	.0090	.0061	.0031
19	6/25	3630	.08	.25	.002	.13	.0006	.0008	.0003
21	7/11	9870	.28	.51	.005	.30	.0016	.0014	.0007
22	7/14	6090	.15	.51	.003	.16	.0006	.0007	.0004
25	8/26	1210	.04	.06	.003	.06	.0004	.0003	.0002
26	8/27	30200	.43	3.51	.031	1.38	.0668	.0098	.0039
28+29	9/1	56900	.57	1.88	.009	1.05	.0027	.0017	.0026
30	9/6	14800	.23	.54	.009	.43	.0024	.0024	.0012
31	9/12	3710	.12	.05	.002	.07	.0003	.0001	.0002
32	9/13	4810	.16	.46	.002	.11	.0003	.0001	.0004
114	7/6/81	48800	.64	2.66	.031	1.55	.0102	.0030	.0033
116	7/13	126000	1.25	6.10	.095	2.86	.0208	.0077	.0100
117	8/31	19500	.12	1.36	.071	1.19	.0023	.0024	.0023
118	9/1	3870	.12	.42	.006	.23	.0012	.0009	.0006
119	9/19	7380	.10	1.24	.012	.53	.0032	.0018	.0009
120	9/20	87100	1.05	6.51	.067	2.88	.0128	.0107	.0059
Total		653930	8.33	38.82	.470	16.70	.1580	.0680	.0462
Average		28432	.36	1.69	.020	.73	.0069	.0030	.0020
Minimum		1210	.04	.05	.001	.06	.0001	.0001	.0002
Maximum		132000	1.33	6.55	.095	2.88	.0668	.0107	.0100

Table A-17. Lake Hills Dry Weather With Street Cleaning (CLHD)

Storm number	Date	Flow (cu ft)	Rain (in)	Total Solids	Runoff Yields (lb/acre/storm) TKN	COD	Total Phos.	Lead	Zinc
34	9/20/80	17300	.25	2.11	.018	.21	.0036	.0041	.0018
85	3/24/81	13000	.21	.57	.007	.26	.0013	.0008	.0007
86	3/28	4700	.14	.19	.002	.11	.0003	.0003	.0003
89	4/5	12500	.18	.67	.006	.32	.0021	.0008	.0007
90	4/6	36900	.34	3.05	.026	.95	.0111	.0045	.0029
91	4/7	16300	.28	.42	.002	.27	.0015	.0005	.0007
92	4/10	26000	.36	1.86	.009	.52	.0037	.0016	.0015
93	4/12	7340	.12	.71	.004	.13	.0023	.0004	.0005
94	4/20	8350	.19	.40	.005	.25	.0011	.0010	.0005
95	4/21	17600	.27	.82	.006	.38	.0017	.0011	.0007
96	4/23	2880	.08	.08	.001	.07	.0002	.0002	.0002
97	4/27	30300	.53	1.48	.022	.66	.0046	.0037	.0013
101	5/11	25400	.43	3.72	.014	1.05	.0040	.0016	.0019
102	5/14	12500	.18	1.23	.011	.48	.0017	.0023	.0014
103	5/14	4680	.08	.56	.005	.20	.0011	.0009	.0004
104	5/18	23700	.44	.86	.009	.39	.0019	.0015	.0016
105	5/24	20500	.36	1.22	.008	.62	.0024	.0025	.0015
106	6/5	27700	.43	1.98	.033	.76	.0092	.0034	.0022
107	6/8	29100	.40	1.30	.018	.64	.0045	.0018	.0016
108	6/9	4190	.08	.47	.004	.05	.0003	.0003	.0004
109	6/12	16200	.28	1.02	.009	.34	.0028	.0020	.0011
110	6/12	11000	.21	.73	.007	.51	.0012	.0013	.0007
112	6/17	12500	.37	.21	.004	.17	.0008	.0008	.0005
113	6/30	21900	.33	2.76	.054	1.64	.0158	.0067	.0035
Total		402540	6.54	28.40	.285	10.97	.0792	.0439	.0285
Average		16773	.27	1.18	.012	.46	.0033	.0018	.0012
Minimum		2880	.08	.08	.001	.05	.0002	.0002	.0002
Maximum		36900	.53	3.72	.054	1.64	.0158	.0067	.0035

Table A-18. Lake Hills Wet Weather Without Street Cleaning (LHW)

Storm number	Month	Flow (cu ft)	Rain (in)	Runoff Yields (lb/acre/storm) Total Solids	TKN	COD	Total Phos.	Lead	Zinc
50	11/27/80	86400	.70	4.39	.048	1.47	.0079	.0053	.0085
51	11/28	103200	.83	4.17	.016	1.47	.0082	.0032	.0042
54	12/4	13900	.23	.53	.007	.23	.0010	.0009	.0007
55	12/14	14500	.17	1.35	.006	.69	.0028	.0027	.0020
56	12/20	37200	.43	2.48	.016	.82	.0055	.0046	.0023
57	12/21	70700	.60	4.89	.033	1.44	.0091	.0043	.0061
58	12/24	23700	.26	1.74	.016	.66	.0032	.0029	.0020
59	12/24	57500	.44	3.27	.025	1.95	.0049	.0035	.0039
61	12/26	53000	.32	2.21	.019	.75	.0039	.0032	.0042
62	12/29	158000	1.11	5.81	.051	2.09	.0097	.0097	.0145
127	10/8/81	42600	.27	2.11	.007	.76	.0026	.0026	.0013
129	10/28	12500	.20	.36	.005	.18	.0010	.0004	.0006
130	10/29	5640	.07	.22	.003	.10	.0006	.0007	.0003
131	10/30	3060	.07	.16	.002	.07	.0003	.0001	.0002
132	11/11	189000	1.58	6.13	.084	3.82	.0243	.0116	.0075
133	11/13	11400	.14	.35	.004	.29	.0011	.0007	.0006
134	11/17	60900	.53	1.23	.010	.82	.0045	.0037	.0028
135+136	11/20	199000	1.44	5.61	.046	3.66	.0146	.0061	.0089
137	11/30	3610	.12	.08	.001	.06	.0003	.0001	.0003
140	12/3	12400	.16	.90	.010	.29	.0009	.0008	.0006
141	12/4	209000	1.43	13.82	.118	3.84	.0166	.0128	.0059
148	12/9	111000	.84	6.46	.029	1.36	.0058	.0034	.0020
149	12/13	29700	.30	1.11	.005	.47	.0027	.0018	.0012
150	12/14	132000	.96	5.01	.040	1.70	.0089	.0081	.0043
151	12/17	21800	.21	.60	.004	.23	.0009	.0013	.0007
152	12/18	111000	.69	3.47	.033	1.29	.0053	.0068	.0060
153	12/21	8670	.09	.27	.003	.13	.0004	.0005	.0004
154	12/23	23400	.26	.47	.004	.29	.0010	.0007	.0006
155	12/28	9160	.10	.33	.008	.22	.0007	.0003	.0005
156	1/10/82	25500	.35	3.54	.021	1.20	.0053	.0062	.0023
158	1/15	106000	.98	5.06	.031	1.62	.0071	.0065	.0051
159	1/17	20600	.18	1.03	.008	.42	.0015	.0013	.0008
Total		1966040	16.06	89.18	.713	34.36	.1628	.1167	.1014
Average		61439	.50	2.79	.022	1.07	.0051	.0036	.0032
Minimum		3060	.07	.08	.001	.06	.0003	.0001	.0002
Maximum		209000	1.58	13.82	.118	3.84	.0243	.0128	.0145

Table A-19. Lake Hills Wet Weather With Street Cleaning (CLHW)

Storm number	Month	Flow (cu ft)	Rain (in)	Runoff Yields (lb/acre/storm) Total Solids	TKN	COD	Total Phos.	Lead	Zinc
37	10/8/80	2590	.11	.27	.006	.12	.0004	.0004	.0003
38	10/12	6780	.16	.11	.003	.09	.0008	.0004	.0003
39	10/24	8140	.17	.69	.006	.40	.0019	.0014	.0009
40+41	10/31	58200	.74	3.78	.034	1.45	.0075	.0064	.0046
42	11/1	38700	.36	4.46	.035	1.50	.0071	.0073	.0028
43	11/3	47500	.52	2.47	.018	1.02	.0047	.0029	.0067
45	11/8	42200	.41	1.76	.017	.93	.0036	.0026	.0019
46	11/14	9710	.15	.74	.004	.50	.0010	.0009	.0007
47	11/19	17400	.19	4.71	.020	.41	.0098	.0027	.0017
48	11/20	223000	1.55	12.56	.142	4.42	.0396	.0137	.0117
49	11/23	17100	.22	.75	.010	.23	.0054	.0016	.0012
63	1/17/81	8460	.15	.74	.004	.23	.0026	.0010	.0008
66	1/23	53000	.48	5.23	.031	1.86	.0091	.0097	.0031
67	1/26	11000	.16	.55	.002	.16	.0018	.0003	.0004
69	1/28	75000	.60	3.17	.011	.61	.0012	.0046	.0024
70+71	2/11	90200	1.00	4.97	.035	2.37	.0122	.0077	.0039
72	2/13	19900	.24	.80	.003	.33	.0016	.0012	.0007
73+74	2/13	113200	1.01	15.11	.087	2.29	.0312	.0208	.0083
76	2/17	10600	.16	.48	.005	.20	.0010	.0010	.0005
77+78	2/18	51080	.58	.00	.044	1.74	.0106	.0091	.0038
Total		903760	8.96	63.35	.517	20.86	.1532	.0958	.0568
Average		45188	.45	3.17	.026	1.04	.0077	.0048	.0028
Minimum		2590	.11	.00	.002	.09	.0004	.0003	.0003
Maximum		223000	1.55	15.11	.142	4.42	.0396	.0208	.0117

Table A-20. Surrey Downs Dry Weather Without Street Cleaning (SDD)

Storm number	Date	Flow (cu ft)	Rain (in)	Runoff Yields (lb/acre/storm) Total Solids	TKN	COD	Total Phos.	Lead	Zinc
1	3/12/80	108000	1.23	4.95	.040	1.63	.0092	.0071	.0055
2	3/26	8550	.19	1.29	.007	.44	.0018	.0020	.0012
21	7/11	10700	.22	1.00	.009	.48	.0020	.0015	.0011
22	7/14	6150	.15	.51	.001	.15	.0006	.0004	.0005
23	8/17	31800	.63	13.00	.061	3.17	.0175	.0171	.0077
25	8/26	2670	.08	.19	.006	.22	.0017	.0009	.0005
26	8/27	8450	.18	1.47	.011	.56	.0065	.0027	.0012
27	8/28	23600	.37	2.23	.013	.54	.0014	.0031	.0017
28	9/1	31400	.50	1.19	.014	.60	.0025	.0010	.0017
30	9/6	11900	.27	.70	.010	.37	.0024	.0017	.0023
31	9/12	1970	.08	.09	.000	.03	.0001	.0001	.0001
32	9/13	5020	.14	.30	.003	.14	.0004	.0002	.0005
33	9/19	2870	.09	.15	.002	.11	.0004	.0002	.0002
34	9/20	20300	.38	2.23	.019	1.01	.0048	.0032	.0021
35	9/29	23700	.43	1.79	.014	.65	.0028	.0020	.0017
81	3/3/81	38300	.62	1.61	.014	.68	.0035	.0025	.0020
82	3/5	8310	.10	.45	.005	.18	.0009	.0005	.0005
83	3/15	23300	.28	1.40	.016	1.25	.0034	.0015	.0018
84	3/23	18800	.34	1.01	.010	.42	.0020	.0012	.0011
85	3/24	14600	.26	.73	.006	.69	.0021	.0010	.0010
86	3/28	7400	.18	.30	.001	.16	.0006	.0002	.0004
88	4/2	5700	.23	.71	.006	.37	.0019	.0007	.0006
89	4/5	5250	.16	.20	.003	.15	.0006	.0003	.0003
90	4/6	15700	.38	1.51	.012	.46	.0057	.0021	.0015
91	4/7	4310	.22	.14	.001	.06	.0002	.0001	.0002
92	4/10	8070	.30	.35	.004	.14	.0011	.0005	.0004
93	4/12	3680	.13	.28	.003	.11	.0006	.0005	.0002
94	4/20	1260	.08	NA	NA	NA	NA	NA	NA
95	4/22	2010	.11	.17	.001	.06	.0002	.0001	.0001
97	4/27	25300	.47	1.19	.013	.55	.0031	.0033	.0013
98	5/3	9690	.21	.66	.009	.60	.0018	.0006	.0009
99	5/7	5550	.16	.49	.005	.30	.0011	.0007	.0006
100	5/7	19600	.33	2.41	.020	.78	.0046	.0026	.0017
101	5/10	20500	.29	1.17	.011	.54	.0027	.0013	.0012
104	5/19	11800	.22	.53	.007	.61	.0015	.0008	.0008
105	5/24	16500	.31	.81	.008	.49	.0022	.0011	.0013
106	6/5	17300	.33	1.59	.018	.75	.0034	.0023	.0019
107	6/8	17500	.31	1.00	.009	.60	.0023	.0011	.0011
108	6/9	2160	.05	NA	NA	NA	NA	NA	NA
109	6/12	10600	.23	.91	.007	.35	.0019	.0007	.0008
110	6/12	17100	.33	3.19	.024	1.10	.0068	.0045	.0026
112	6/17	8880	.23	.18	.004	.17	.0010	.0006	.0005
113	6/30	11500	.25	2.44	.032	1.12	.0090	.0030	.0020
114	7/6	26400	.53	1.95	.020	1.02	.0042	.0017	.0024
115	7/10	6230	.16	.61	.007	.42	.0011	.0008	.0007
116	7/13	69800	1.17	3.57	.038	1.46	.0078	.0046	.0056
117	8/31	6340	.24	.82	.013	.34	.0028	.0008	.0011
119	9/18	18800	.50	4.14	.048	1.61	.0110	.0062	.0034
120	9/20	38200	.68	3.40	.032	1.45	.0050	.0050	.0039
121	9/25	33900	.58	2.58	.024	1.27	.0049	.0022	.0034
122	9/26	103000	1.65	10.66	.080	3.37	.0215	.0135	.0079
Total		950420	17.56	84.25	.720	33.75	.1763	.1119	.0832
Average		18635.69	.34	1.72	.015	.69	.0036	.0023	.0017
Minimum		1260	.05	.09	.000	.03	.0001	.0001	.0001
Maximum		108000	1.65	13.00	.080	3.37	.0215	.0171	.0079

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Table A-21. Surrey Downs Dry Weather With Street Cleaning (CSDD)

Storm number	Date	Flow (cu ft)	Rain (in)	Runoff Yields (lb/acre/storm) Total Solids	TKN	COD	Total Phos.	Lead	Zinc
3	4/5/80	22600	.43	1.66	.016	.74	.0037	.0040	.0019
4+5	4/8	48900	.79	4.23	.019	1.25	.0077	.0064	.0035
7	4/14	8590	.18	1.10	.015	.30	.0033	.0019	.0011
8	4/18	78800	1.18	2.22	.026	.77	.0050	.0026	.0048
Total		158890	2.58	9.21	.076	3.07	.0197	.0148	.0113
Average		39723	.65	2.30	.019	.77	.0049	.0037	.0028
Minimum		8590	.18	1.10	.015	.30	.0033	.0019	.0011
Maximum		78800	1.18	4.23	.026	1.25	.0077	.0064	.0048

Table A-22. Surrey Downs Wet Weather Without Street Cleaning (SDW)

Storm number	Date	Flow (cu ft)	Rain (in)	Runoff Yields (lb/acre/storm) Total Solids	TKN	COD	Total Phos.	Lead	Zinc
37	10/8/80	10200	.19	1.16	.013	.26	.0024	.0017	.0012
38	10/12	4280	.12	.15	NA	.07	.0005	.0002	.0002
39	10/24	7760	.16	.71	.005	.52	.0012	.0008	.0008
40	10/31	48500	.74	1.81	.020	1.62	.0048	.0029	.0032
42	11/1	20700	.29	1.36	.015	.62	.0024	.0019	.0013
43	11/3	41600	.60	2.59	.021	.87	.0044	.0016	.0019
44	11/6	87500	1.18	5.33	.036	2.92	.0046	.0057	.0103
45	11/8	36000	.43	1.51	.015	.83	.0033	.0024	.0031
46	11/14	5330	.12	.87	.005	.17	.0008	.0007	.0011
47	11/19	14200	.21	.68	.011	.38	.0016	.0009	.0011
48	11/20	134000	1.66	5.27	.098	2.63	.0132	.0088	.0149
49	11/25	8730	.15	.17	.005	.18	.0015	.0006	.0006
50	11/27	55100	.71	1.77	.020	1.05	.0040	.0018	.0030
51	11/28	87900	.86	3.05	.073	1.96	.0058	.0058	.0045
52	12/2	88000	.97	3.92	.042	2.42	.0098	.0058	.0086
53	12/3	51200	.46	2.38	.008	.87	.0028	.0034	.0027
55	12/14	5050	.11	.33	.003	.23	.0008	.0007	.0004
56	12/20	25100	.43	1.56	.012	.95	.0030	.0016	.0020
58	12/24	16600	.26	1.07	.010	.67	.0017	.0011	.0022
59	12/24	50500	.51	1.98	.008	.66	.0029	.0066	.0029
60	12/25	135000	1.28	6.72	.062	2.39	.0118	.0044	.0097
61	12/26	49900	.34	2.71	.021	.65	.0069	.0016	.0075
62	12/29	127000	1.14	7.57	.047	1.58	.0077	.0042	.0076
63	1/17/81	10400	.22	.85	.007	.32	.0025	.0014	.0010
64	1/20	16600	.27	1.07	.003	.57	.0008	.0011	.0010
65	1/21	35900	.42	2.14	.018	1.13	.0004	.0024	.0016
69	1/28	59100	.63	2.63	.010	.77	.0001	.0039	.0018
70	2/11	63800	.91	3.34	.027	2.17	.0067	.0042	.0040
72 to 78	2/13	249600	2.20	20.44	.160	7.68	.0327	.0262	.0141
79	2/24	34300	.36	1.68	.014	.85	.0038	.0022	.0020
155	12/28	2460	.04	.07	NA	NA	NA	NA	NA
156	1/10/82	17800	.30	3.19	.023	1.28	.0044	.0047	.0023
158	1/15	90800	1.10	6.07	.043	2.26	.0101	.0059	.0061
159	1/17	13800	.16	1.15	.007	.30	.0008	.0009	.0007
Total		1704710	19.53	97.30	.861	41.86	.1601	.1178	.1257
Average		50139	.57	2.86	.027	1.27	.0049	.0036	.0038
Minimum		2460	.04	.07	.003	.07	.0001	.0002	.0002
Maximum		249600	2.20	20.44	.160	7.68	.0327	.0262	.0149

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Table A-23. Surrey Downs Wet Weather With Street Cleaning (CSDW)

Storm number	Date	Flow (cu ft)	Rain (in)	Runoff Yields (lb/acre/storm) Total Solids	TKN	COD	Total Phos.	Lead	Zinc
123	10/1/81	52100	.81	3.24	.025	.96	.0051	.0034	.0027
124+125	10/5	401000	4.38	37.82	.268	8.93	.0604	.0447	.0263
126	10/7	18300	.14	1.39	.011	.29	.0009	.0012	.0008
127	10/8	19200	.24	1.11	.007	.38	.0012	.0013	.0009
128	10/27	39500	.74	1.86	.016	.93	.0040	.0013	.0024
129	10/28	9170	.17	.45	.004	.17	.0009	.0006	.0008
131	10/30	4230	.09	.27	.005	.07	.0008	.0001	.0004
132	11/11	98900	1.50	4.92	.041	2.14	.0110	.0065	.0054
133	11/13	6030	.11	.27	.003	.17	.0006	.0004	.0006
137	11/30	7360	.14	.53	.006	.33	.0013	.0010	.0007
138+139	12/1	37130	.55	2.02	.018	.88	.0043	.0046	.0029
140	12/3	13500	.19	1.24	.006	.42	.0011	.0009	.0008
141	12/4	116000	1.27	8.36	.049	1.29	.0091	.0076	.0061
148	12/9	72800	.78	5.44	.023	1.34	.0043	.0024	.0028
149	12/13	22400	.36	1.16	.009	.51	.0020	.0015	.0014
150	12/14	81100	.87	5.15	.033	1.86	.0080	.0053	.0042
151	12/17	22400	.29	1.95	.009	.40	.0019	.0015	.0016
152	12/19	83100	.79	3.48	.026	1.14	.0046	.0054	.0046
153	12/21	3980	.08	.51	.002	.14	.0005	.0005	.0004
154	12/23	17100	.27	.82	.006	.37	.0013	.0006	.0007
Total		1125300	13.77	81.99	.567	22.72	.1235	.0906	.0665
Average		56265	.69	4.10	.028	1.14	.0062	.0045	.0033
Minimum		3980	.08	.27	.002	.07	.0005	.0001	.0004
Maximum		401000	4.38	37.82	.268	8.93	.0604	.0447	.0263

FIGURE A-1

NUMBER OF RAINS PER MONTH

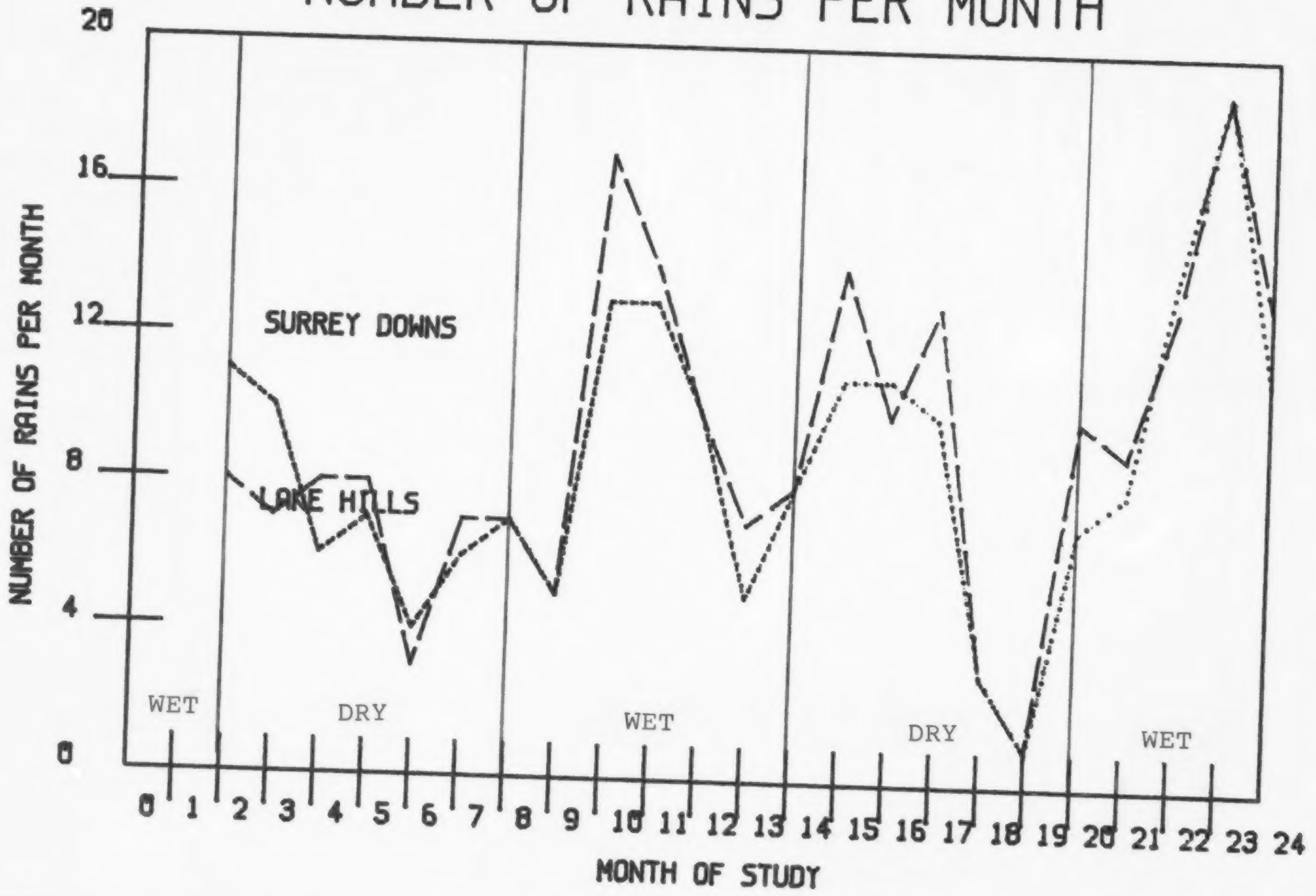

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FIGURE A-2

RAIN VOLUME PER STORM EVENT

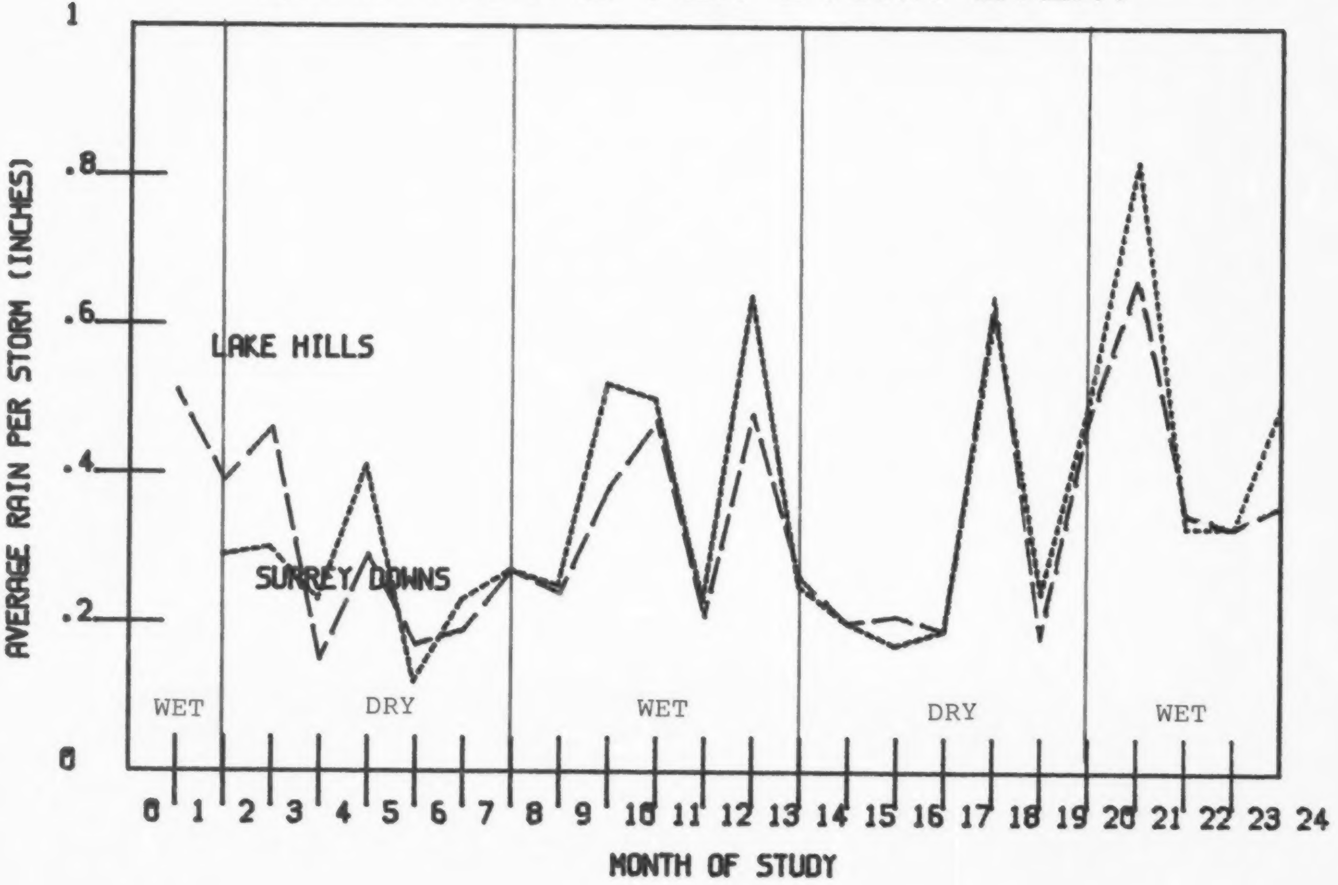

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FIGURE A-3

STORM DURATIONS

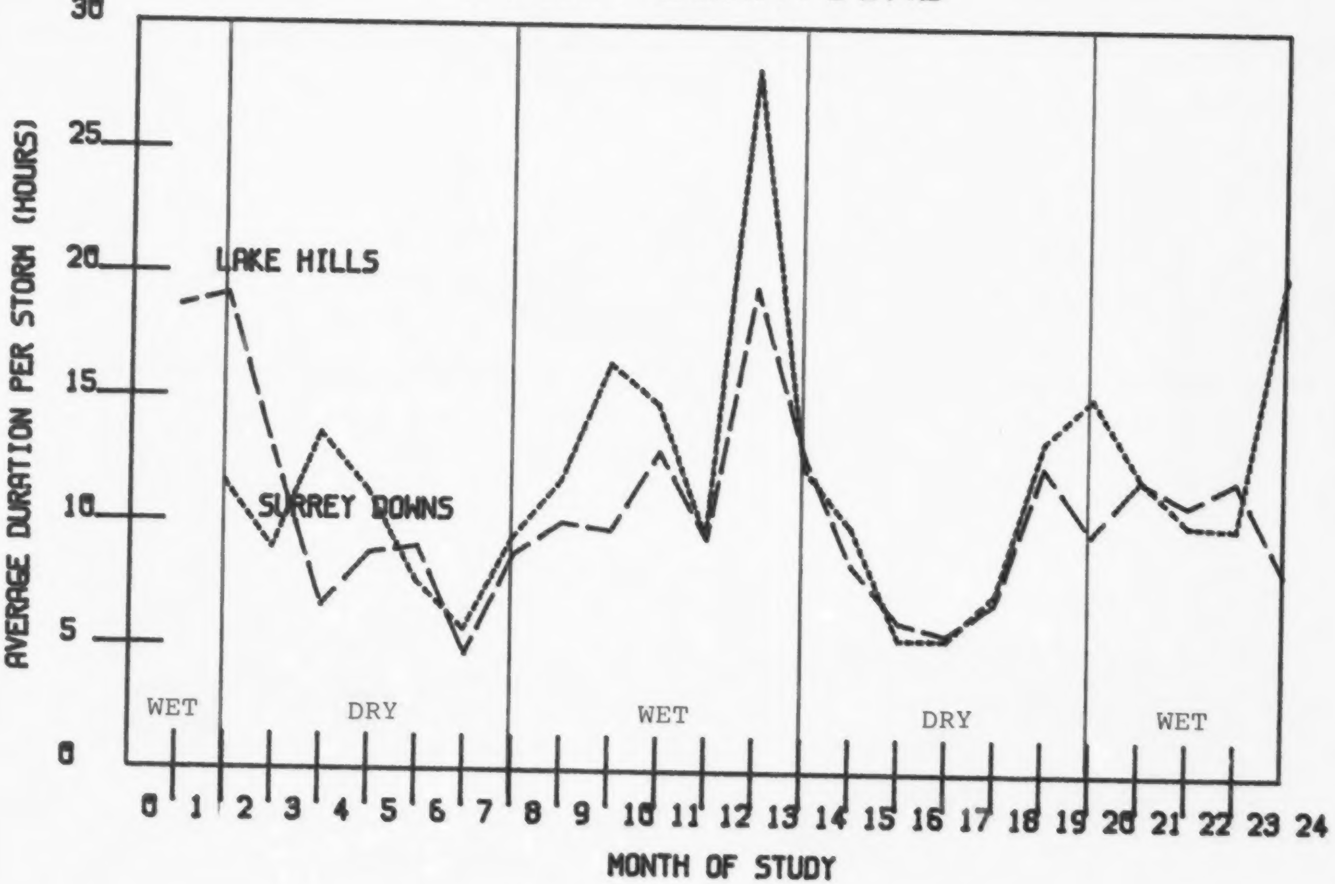

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FIGURE A-4

INTEREVENT PERIOD

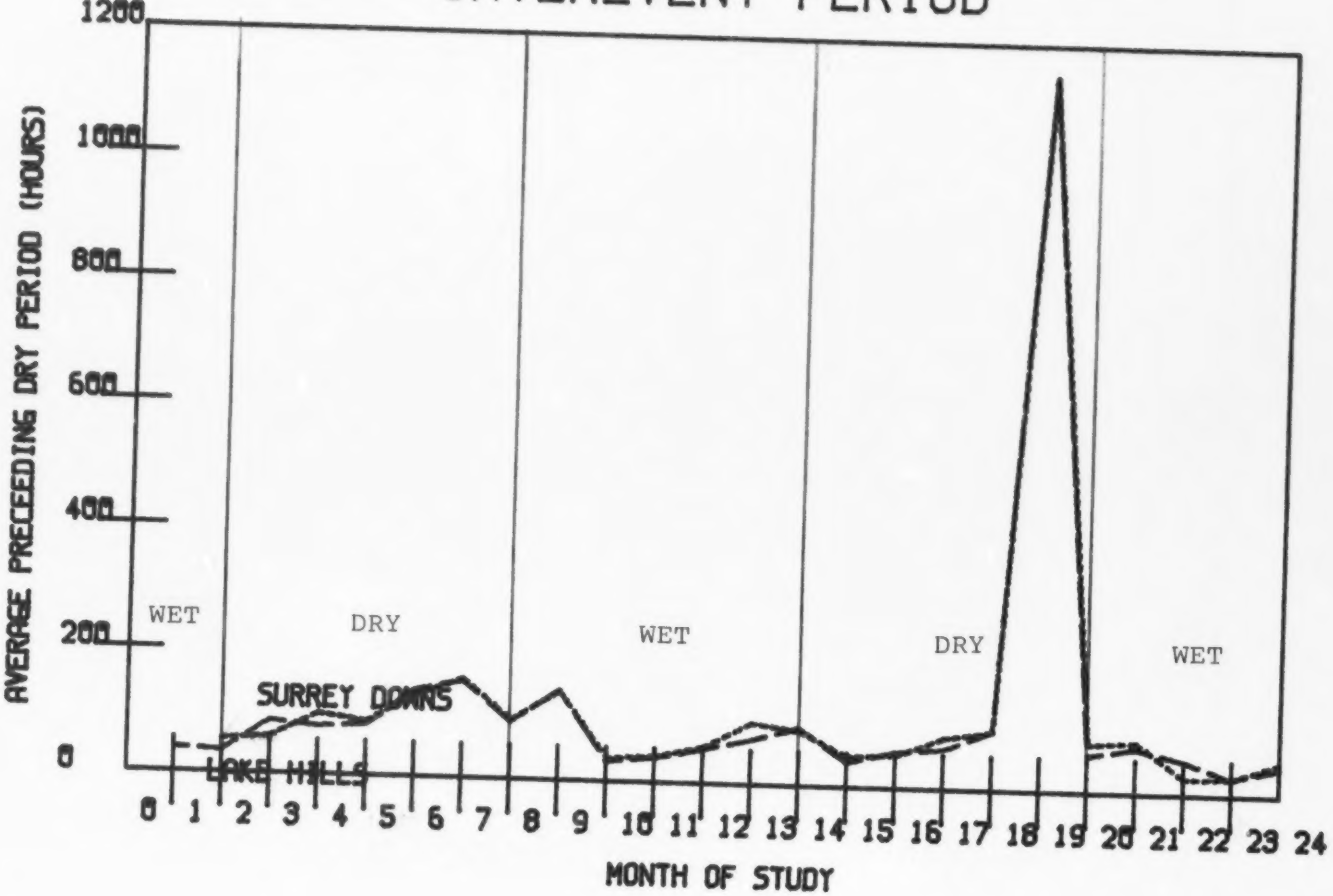

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FIGURE A-5

AVERAGE RAIN INTENSITY

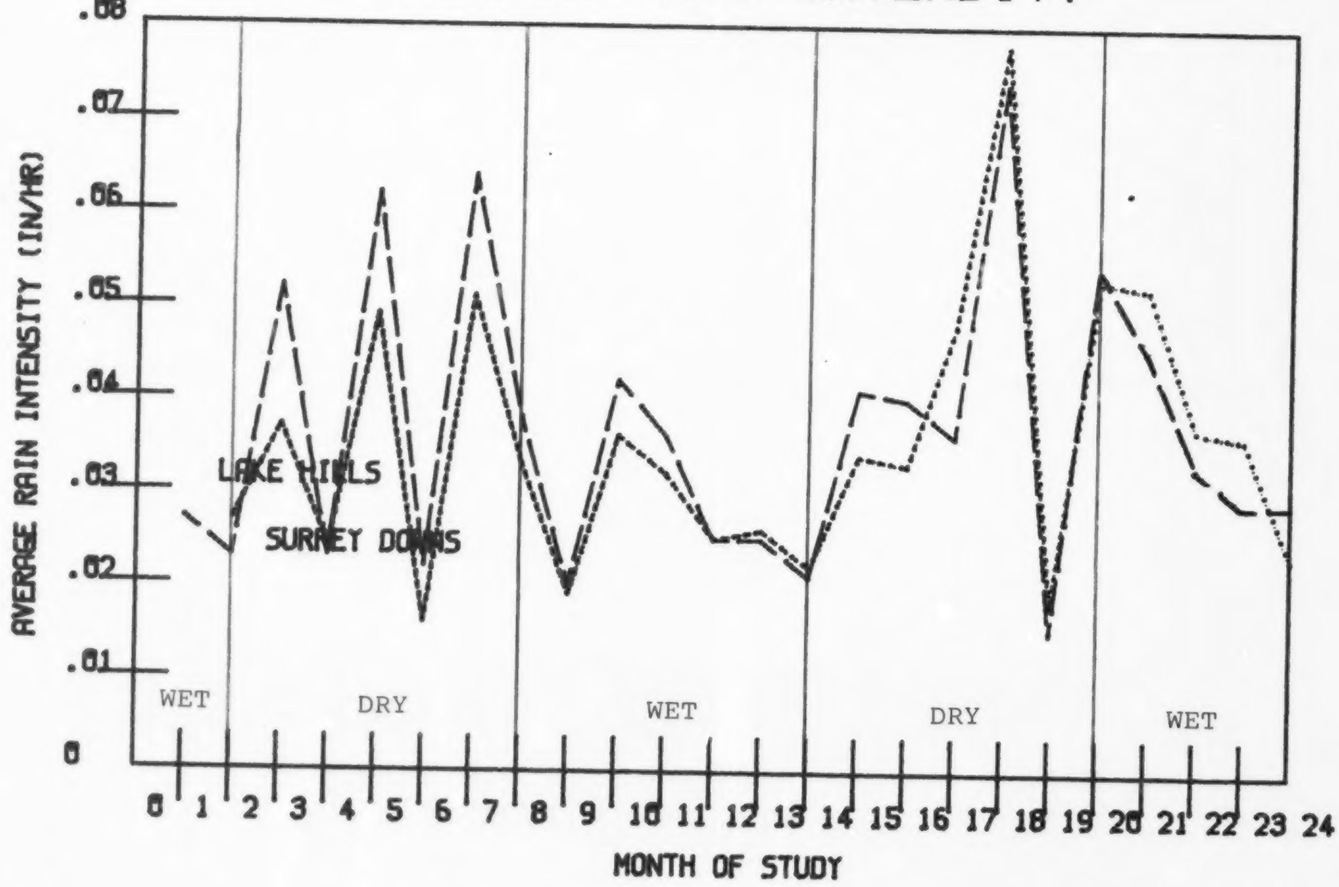

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FIGURE A-6

PEAK RAIN INTENSITY

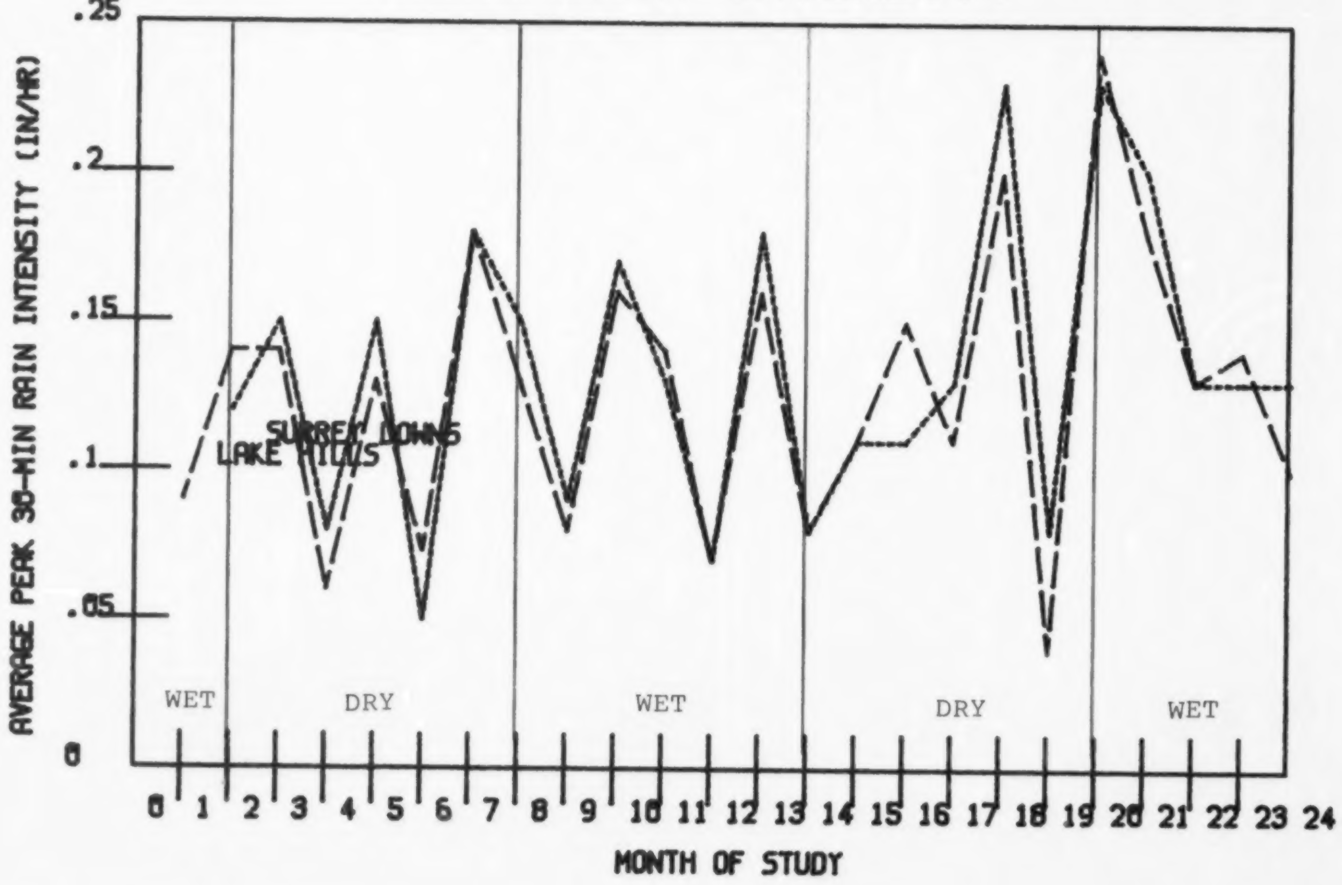

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FIGURE A-7

LAKE HILLS AND SURREY DOWNS RAIN QUANITIES

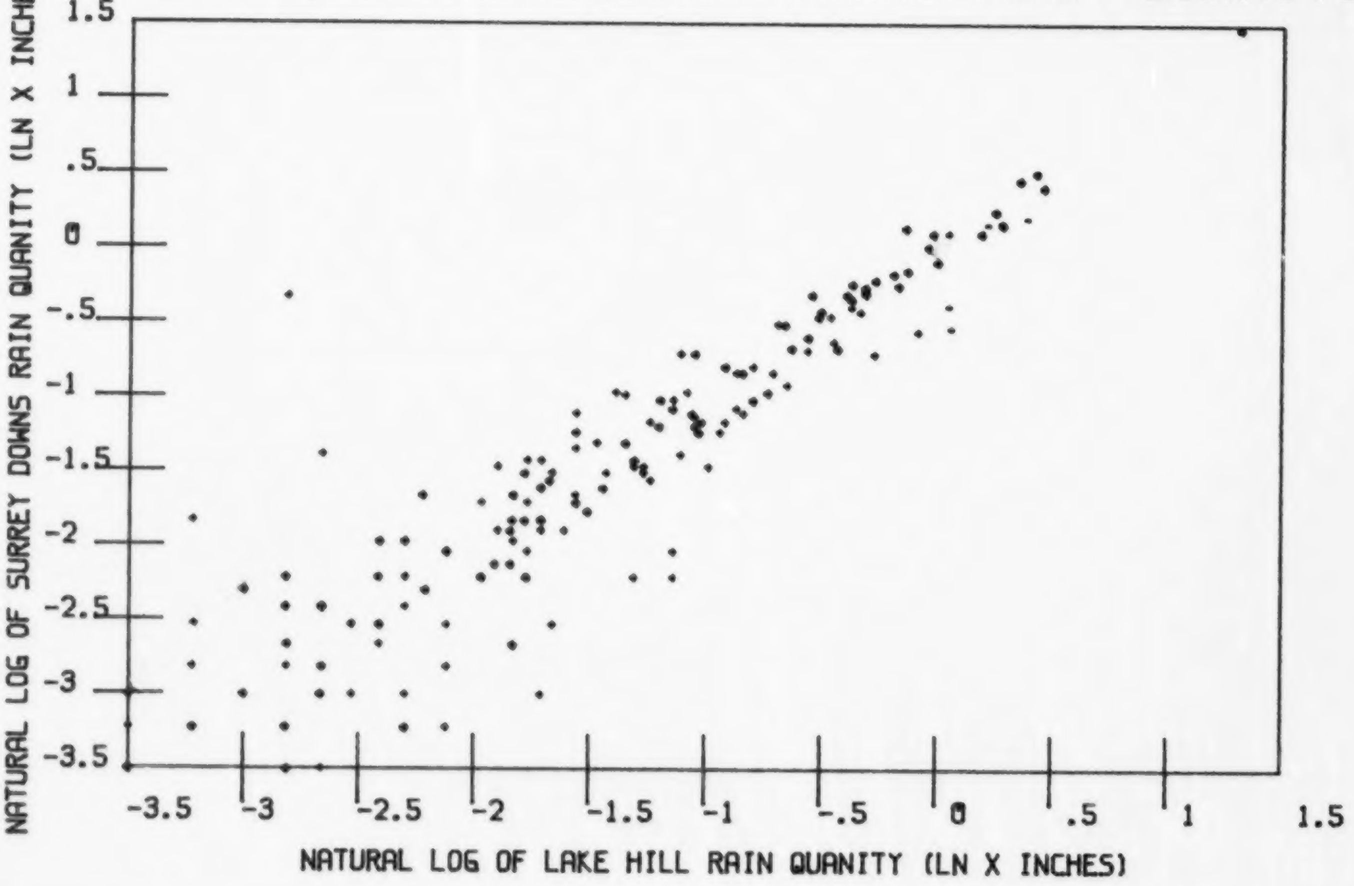

FIGURE A-8

LAKE HILLS AND SURREY DOWNS RAIN DURATIONS

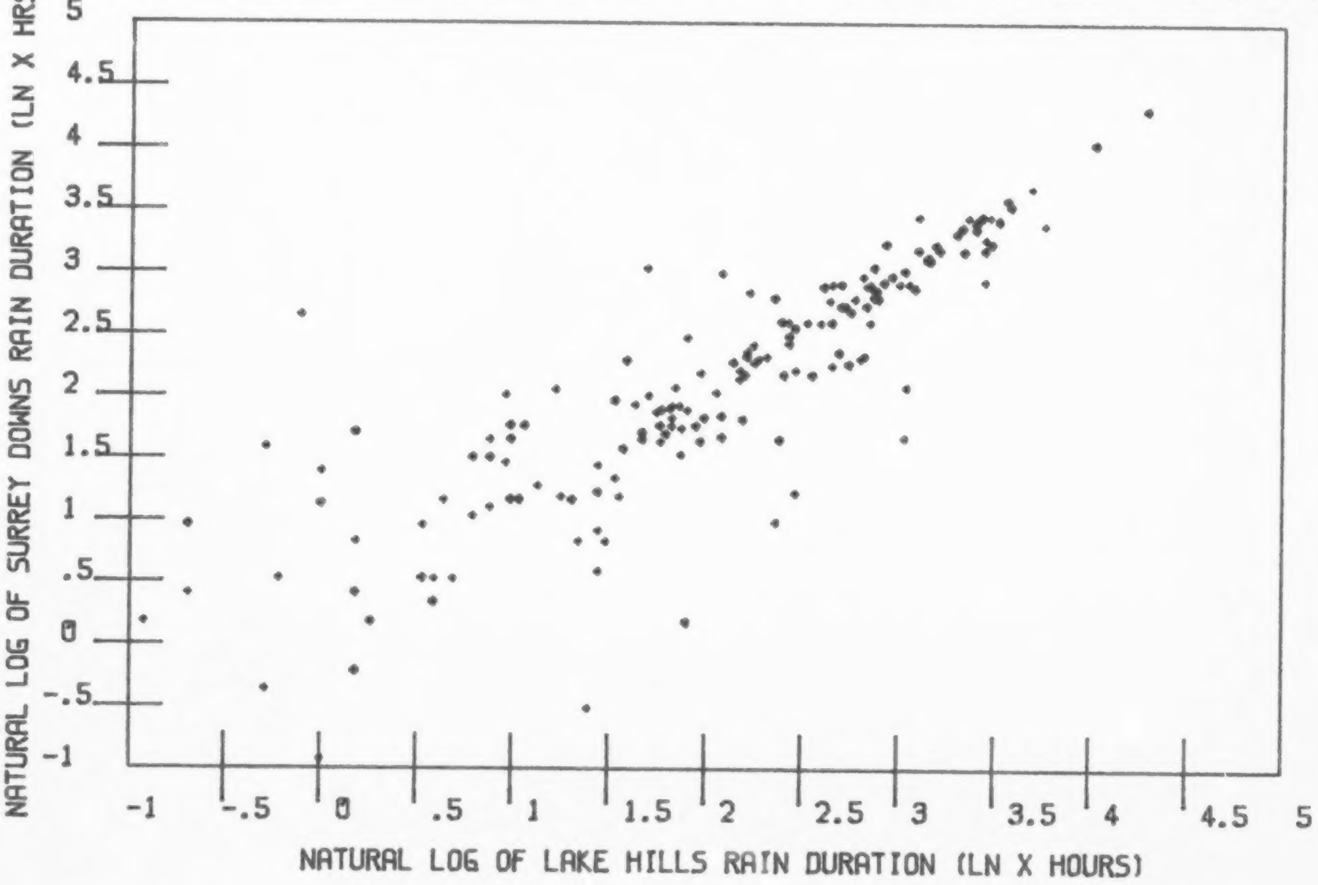

FIGURE A-9

LAKE HILLS AND SURREY DOWNS PEAK RAIN INT.

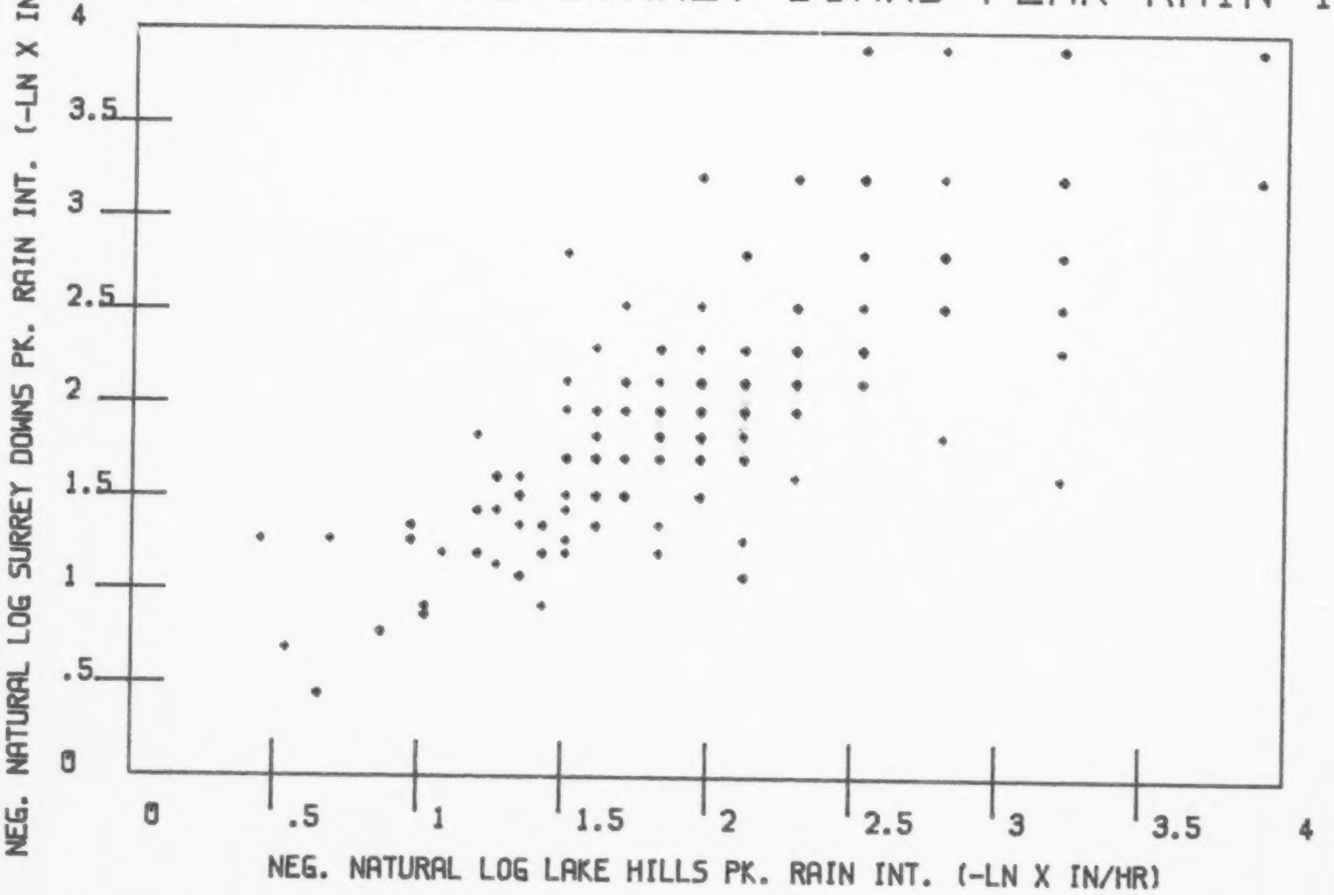

FIGURE A-10

LAKE HILLS - Wet Season

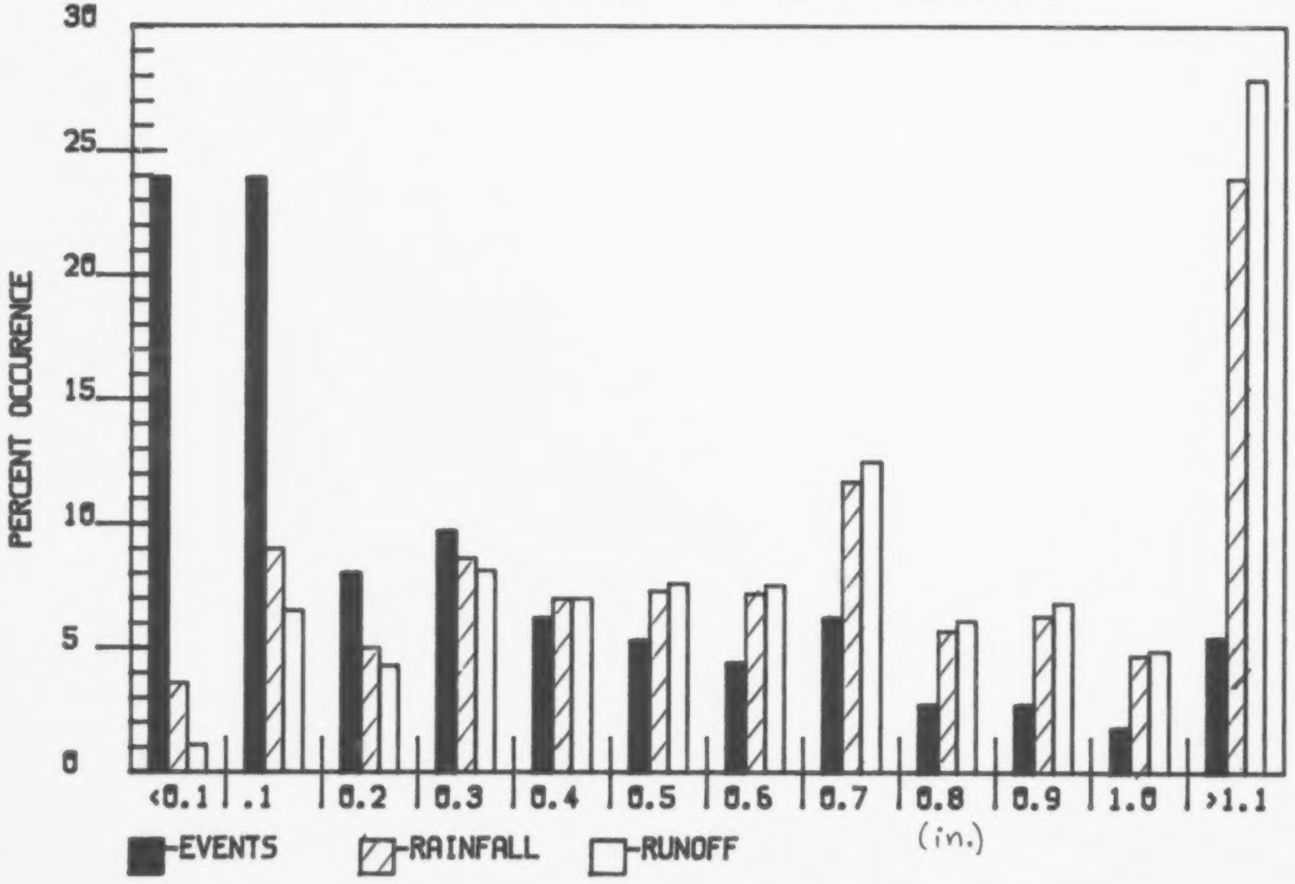

FIGURE A-11

SURREY DOWNS - Wet Season

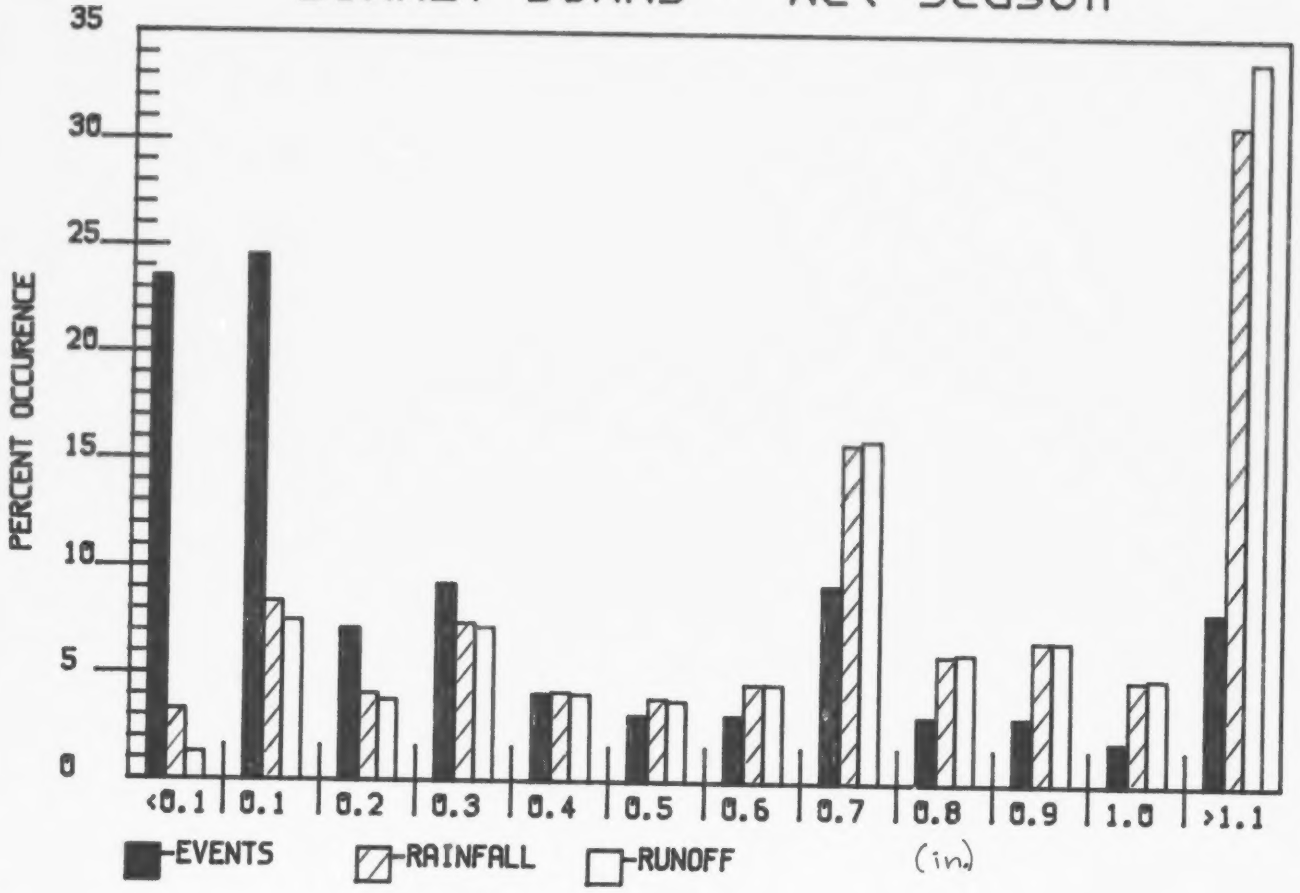

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FIGURE A-12

LAKE HILLS - Dry Season

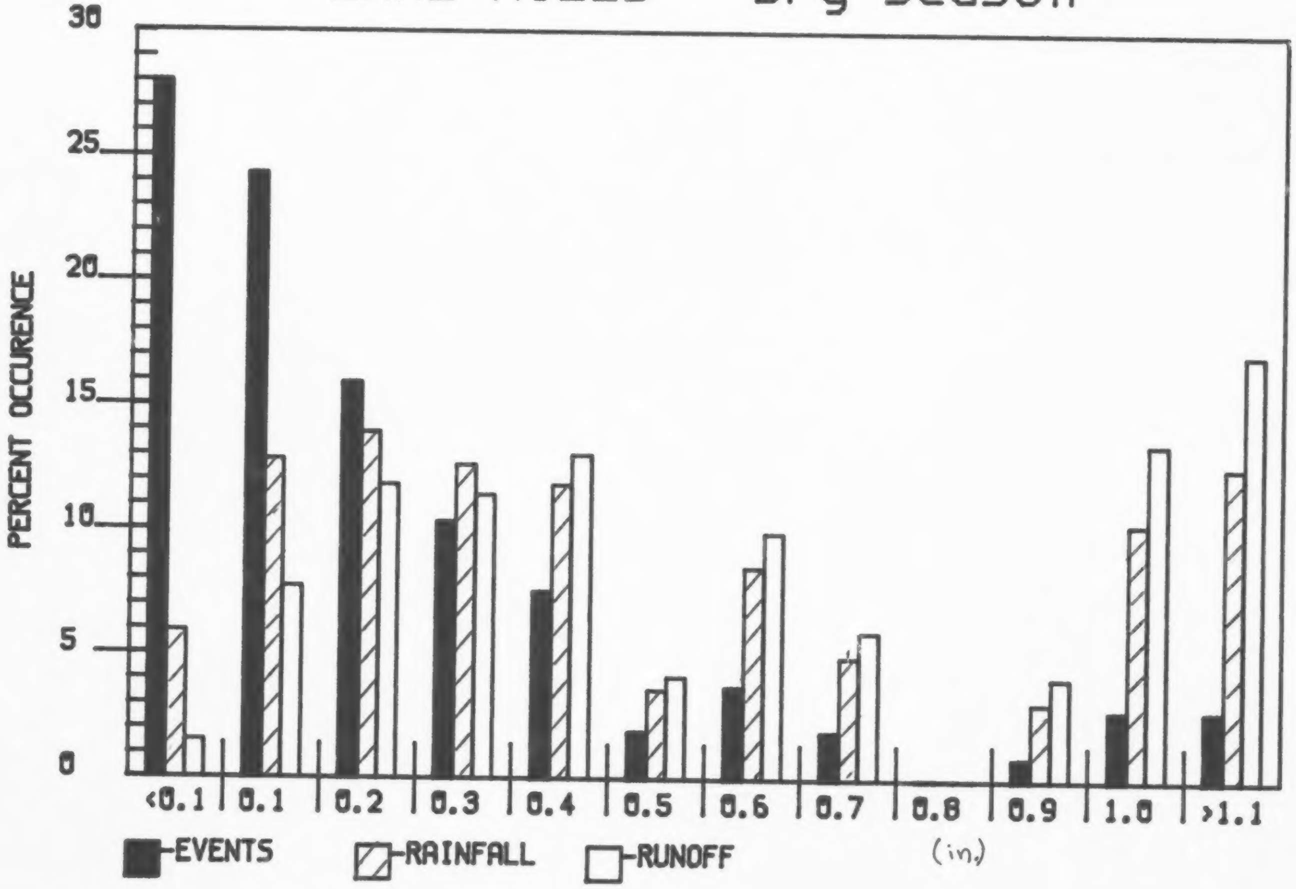

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FIGURE A-13

SURREY DOWNS - Dry Season

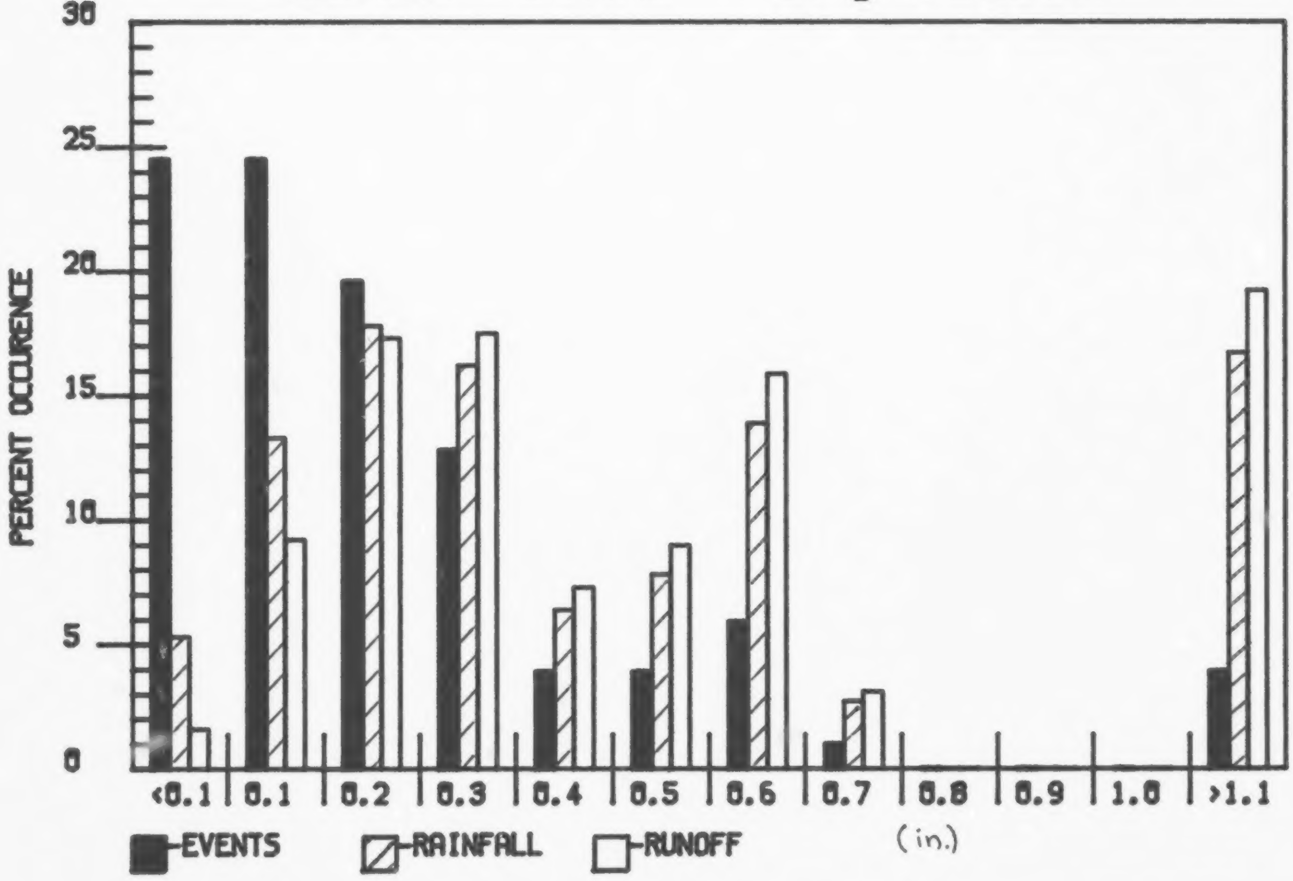

FIGURE A-14

SURREY DOWNS RUNOFF (percent by month)

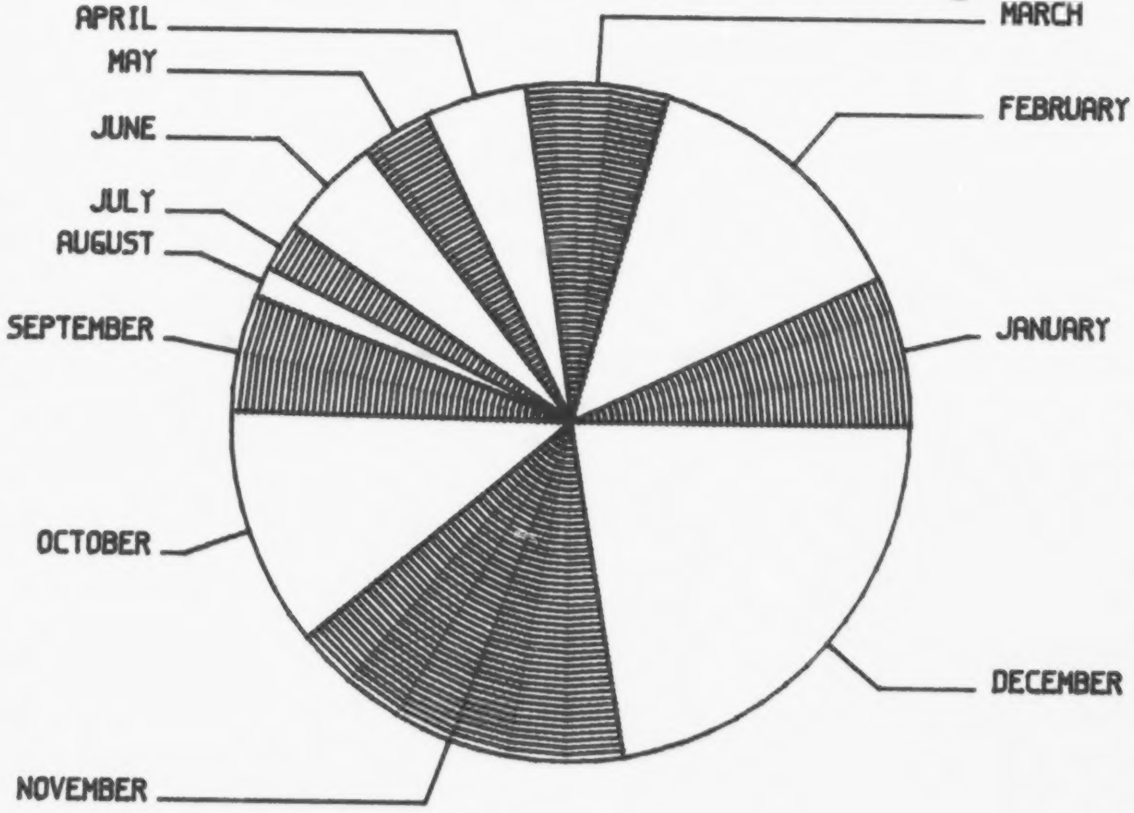

FIGURE A-15

SURREY DOWNS BASE FLOWS (percent by month)

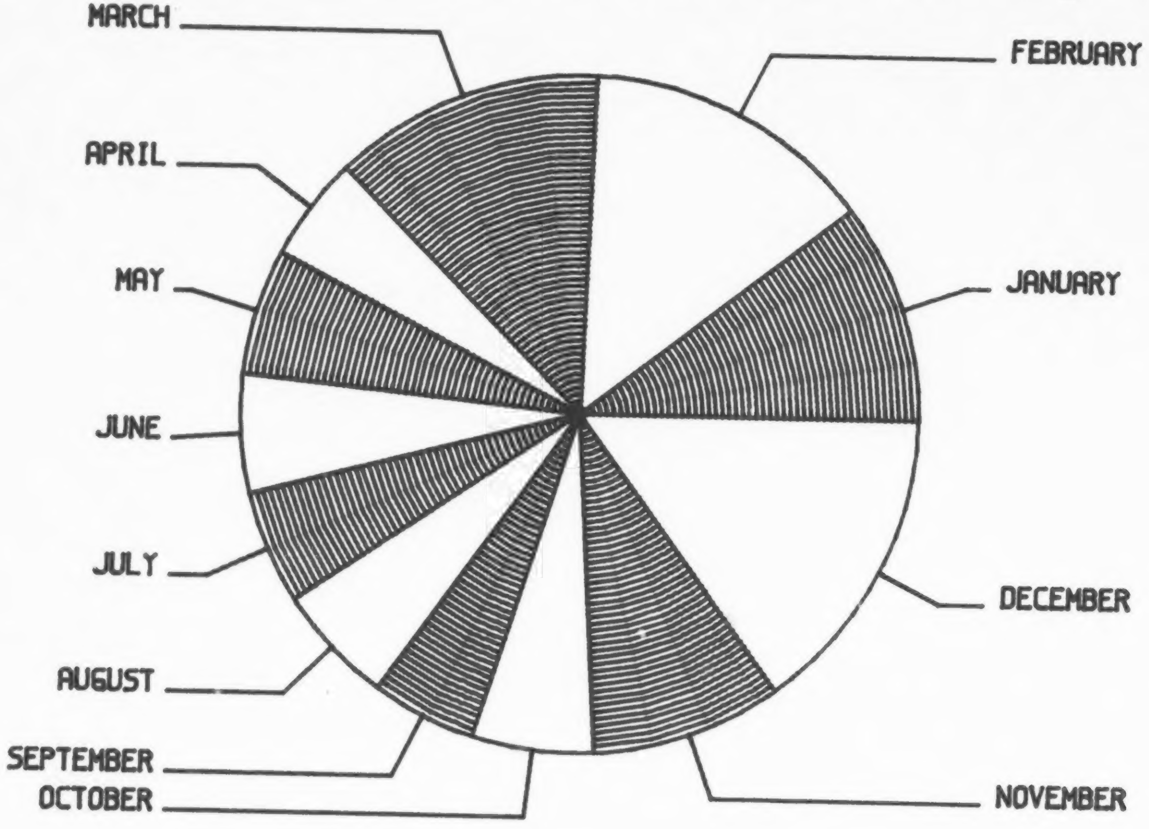

FIGURE A-16

LEAD

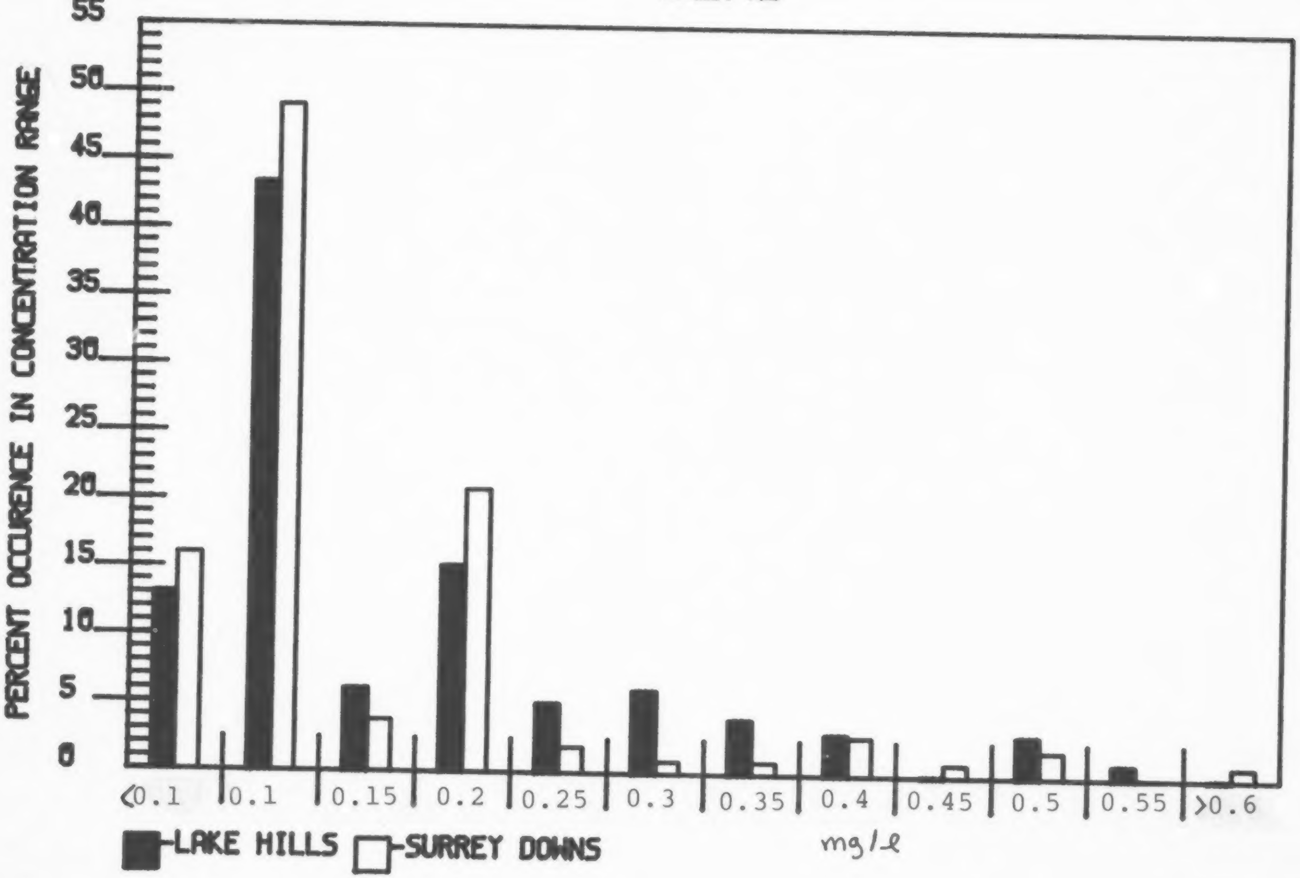

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FIGURE A-17

ZINC

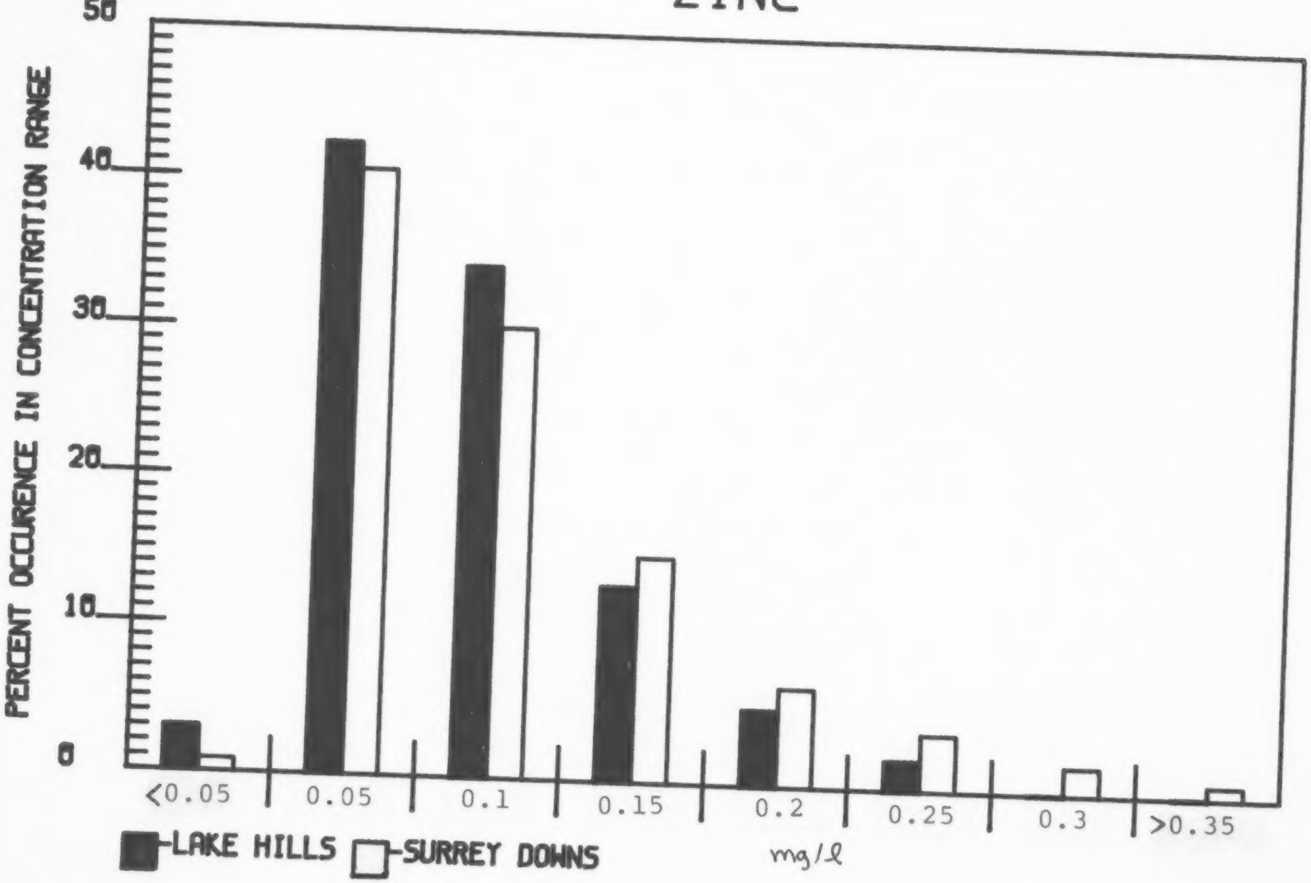

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FIGURE A-18

CHEMICAL OXYGEN DEMAND

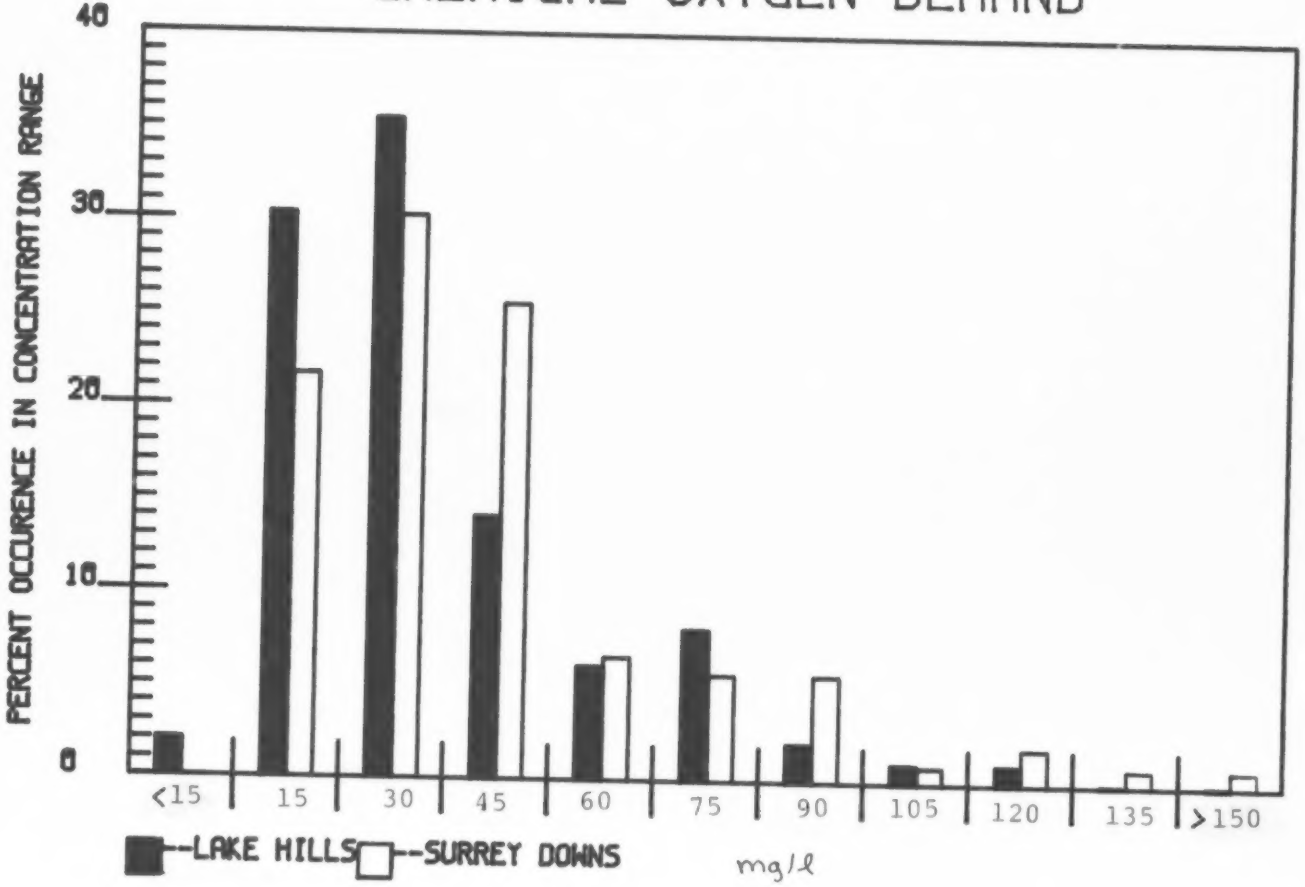


FIGURE A-19

TOTAL KJELDAHL NITROGEN

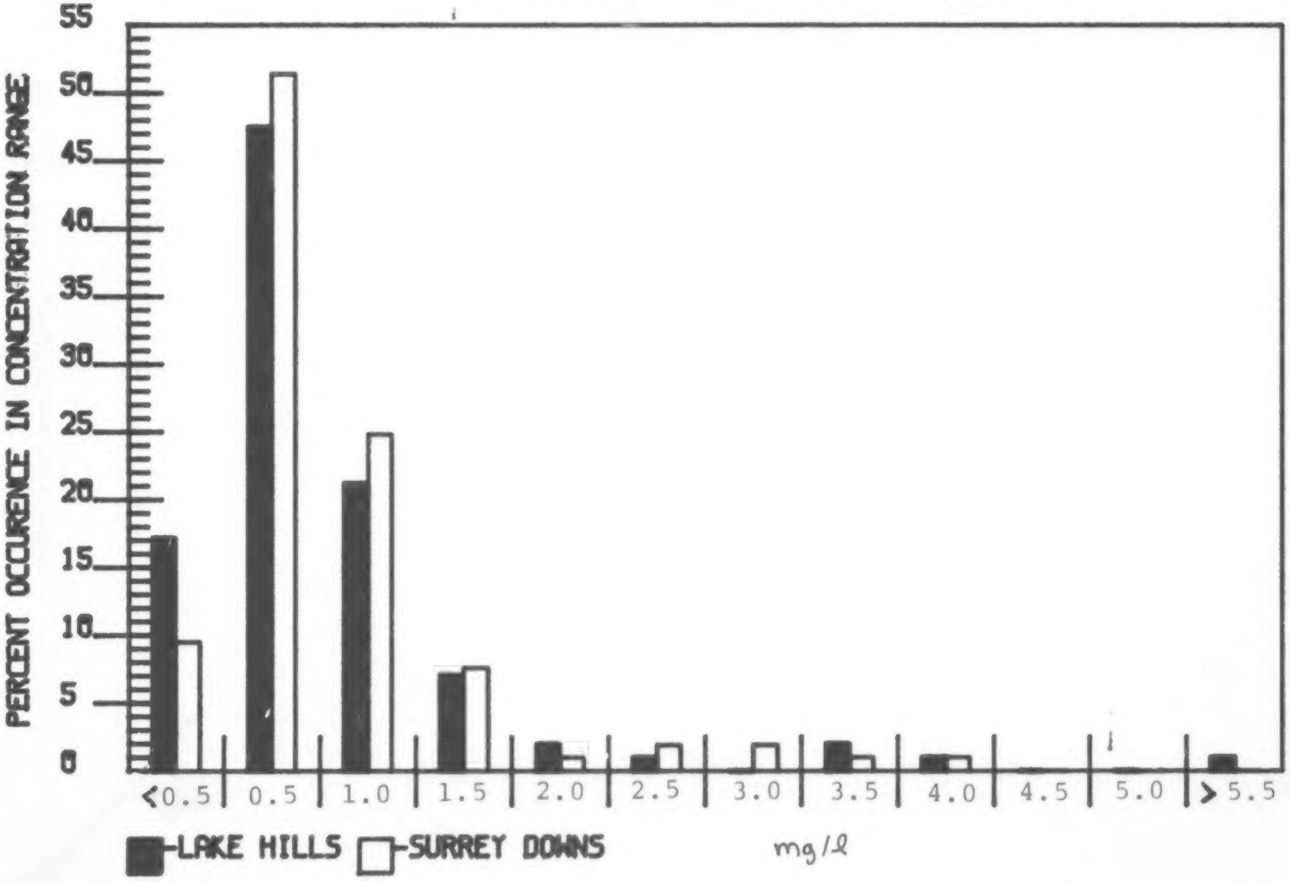


FIGURE A-20

TOTAL PHOSPHOROUS

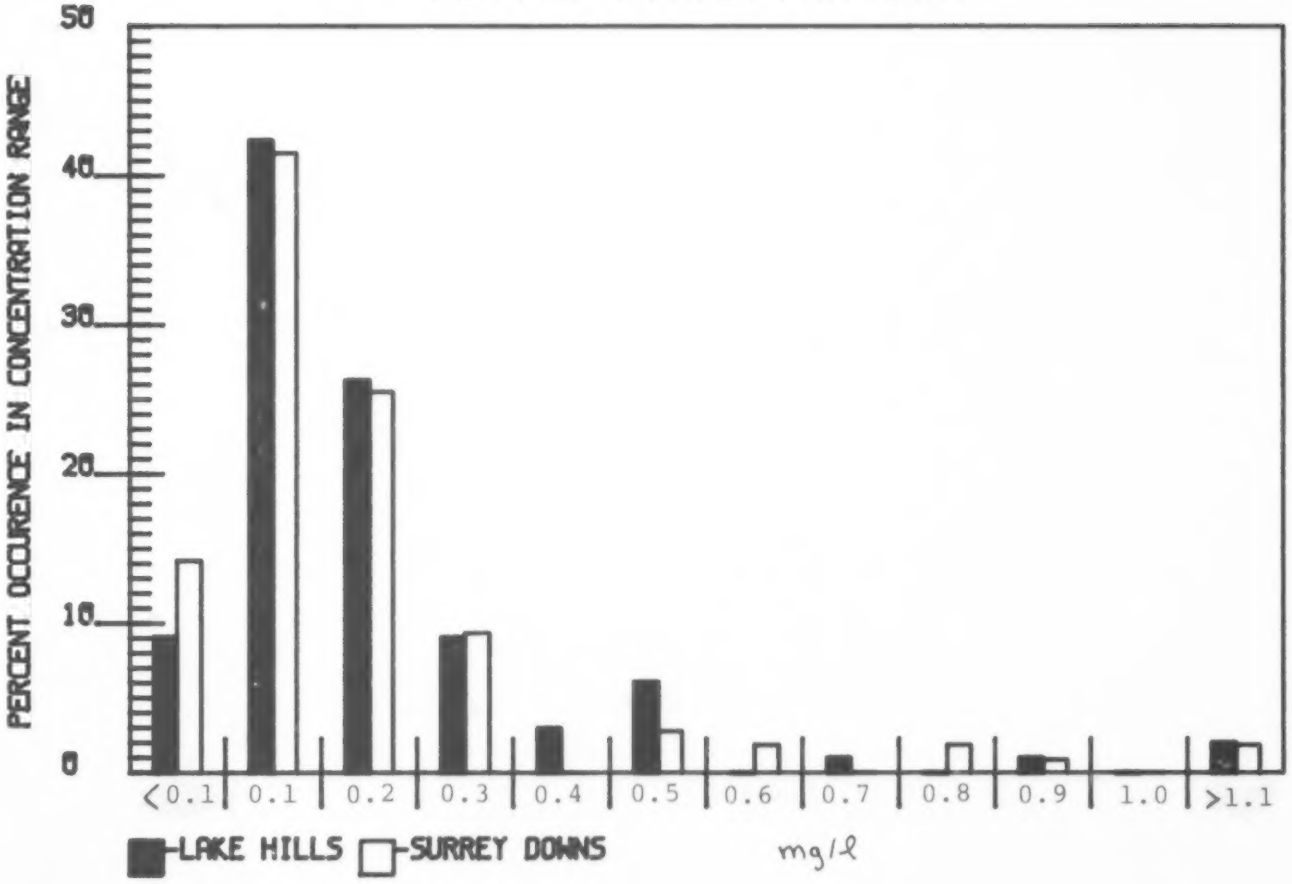


FIGURE A-21

PH

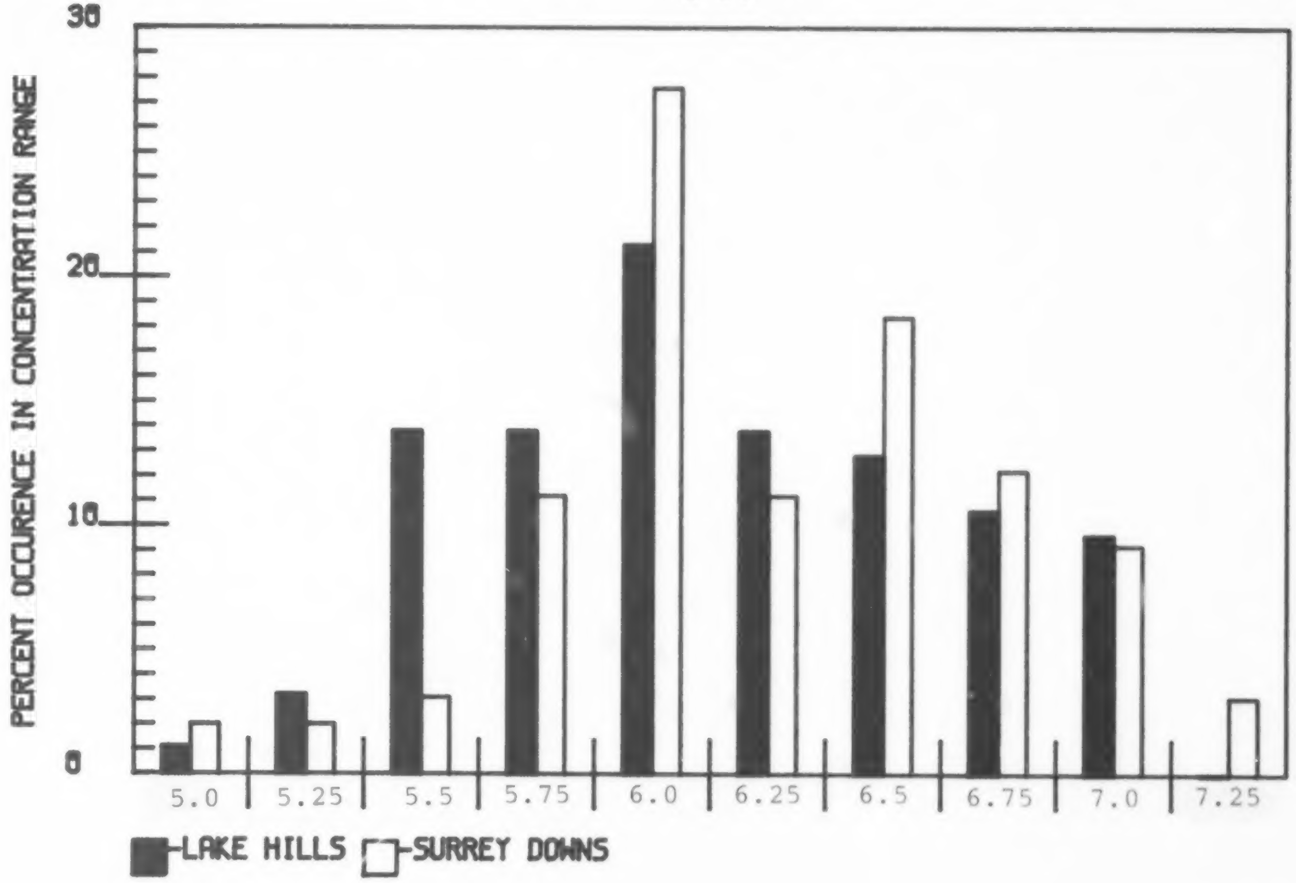


FIGURE A-22

SPECIFIC CONDUCTANCE

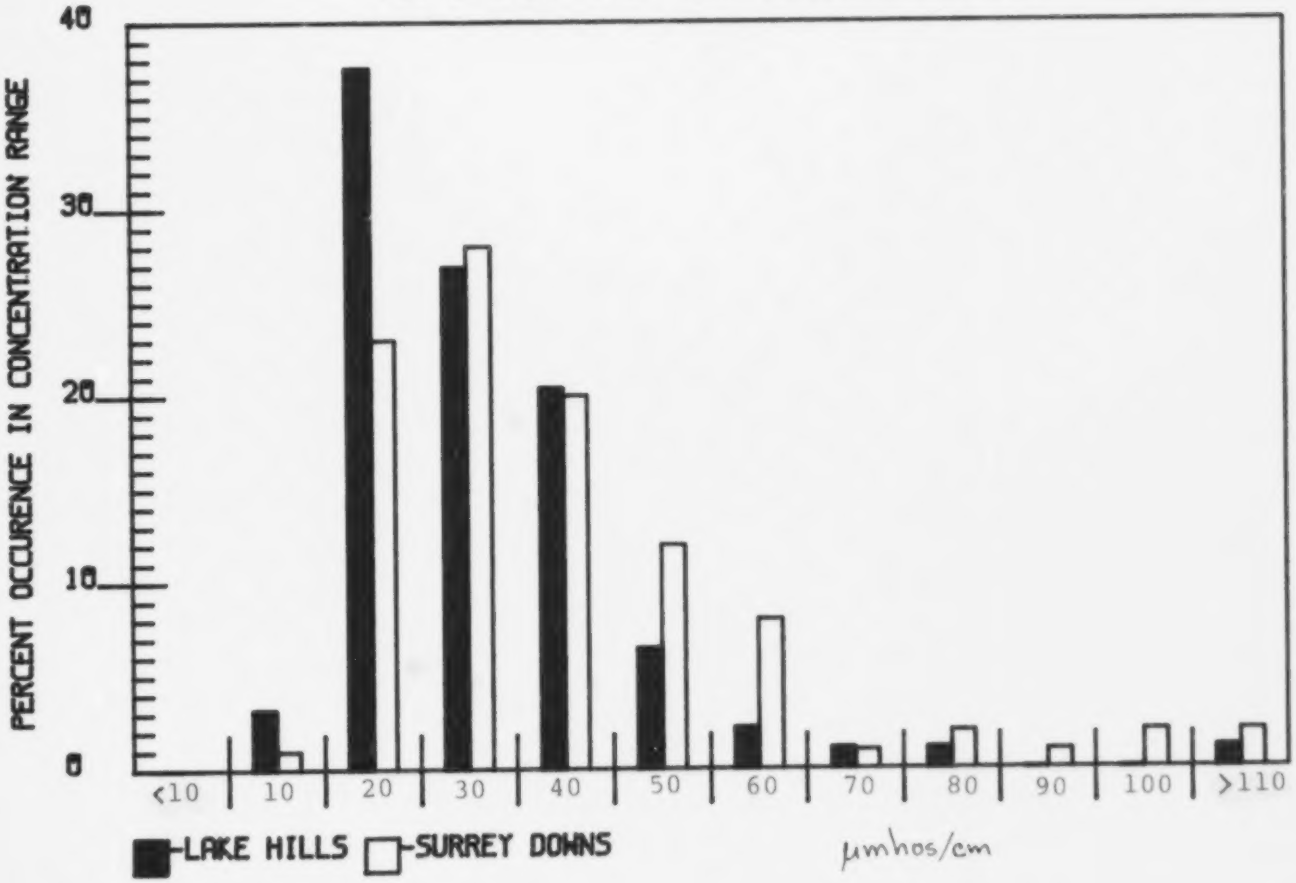
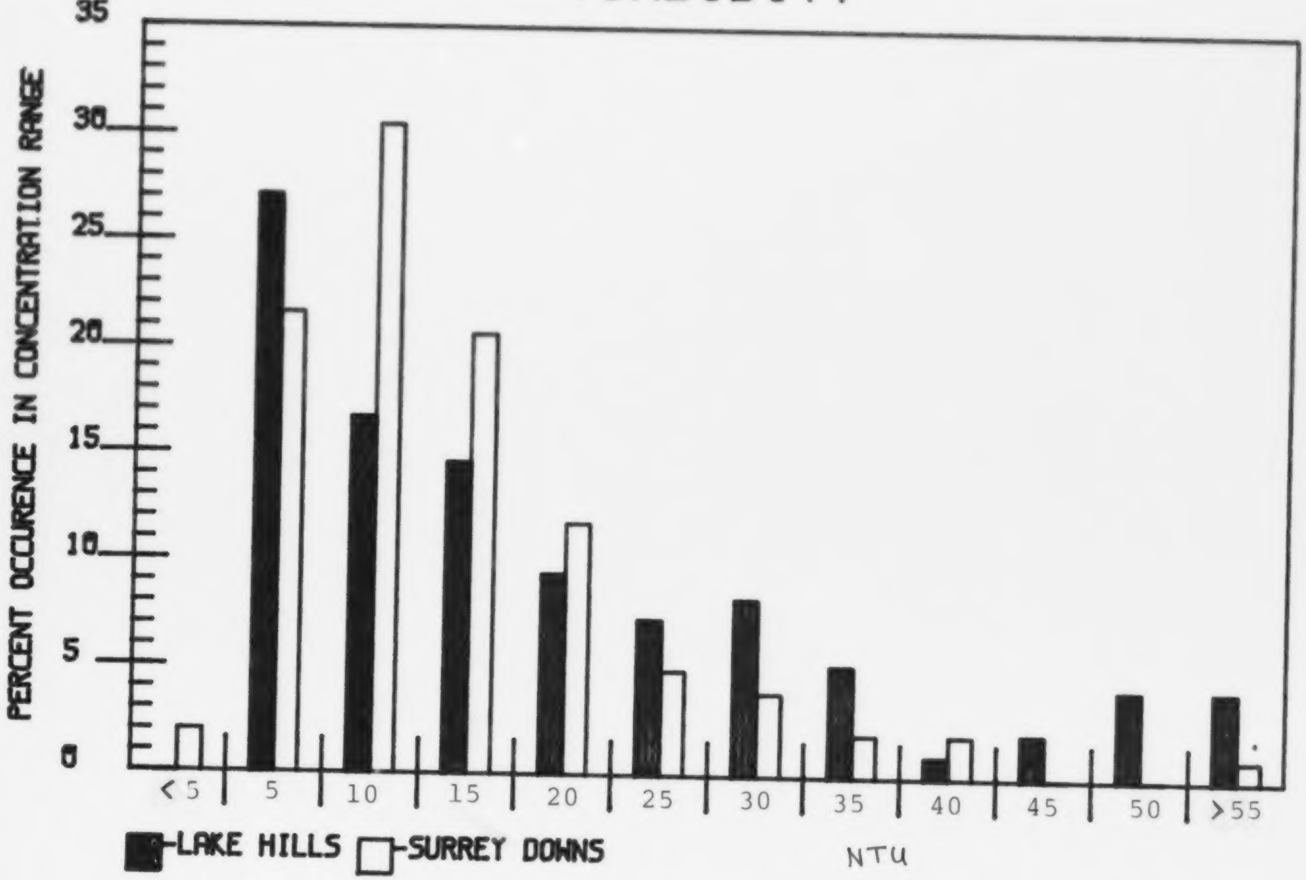


FIGURE A-23

TURBIDITY



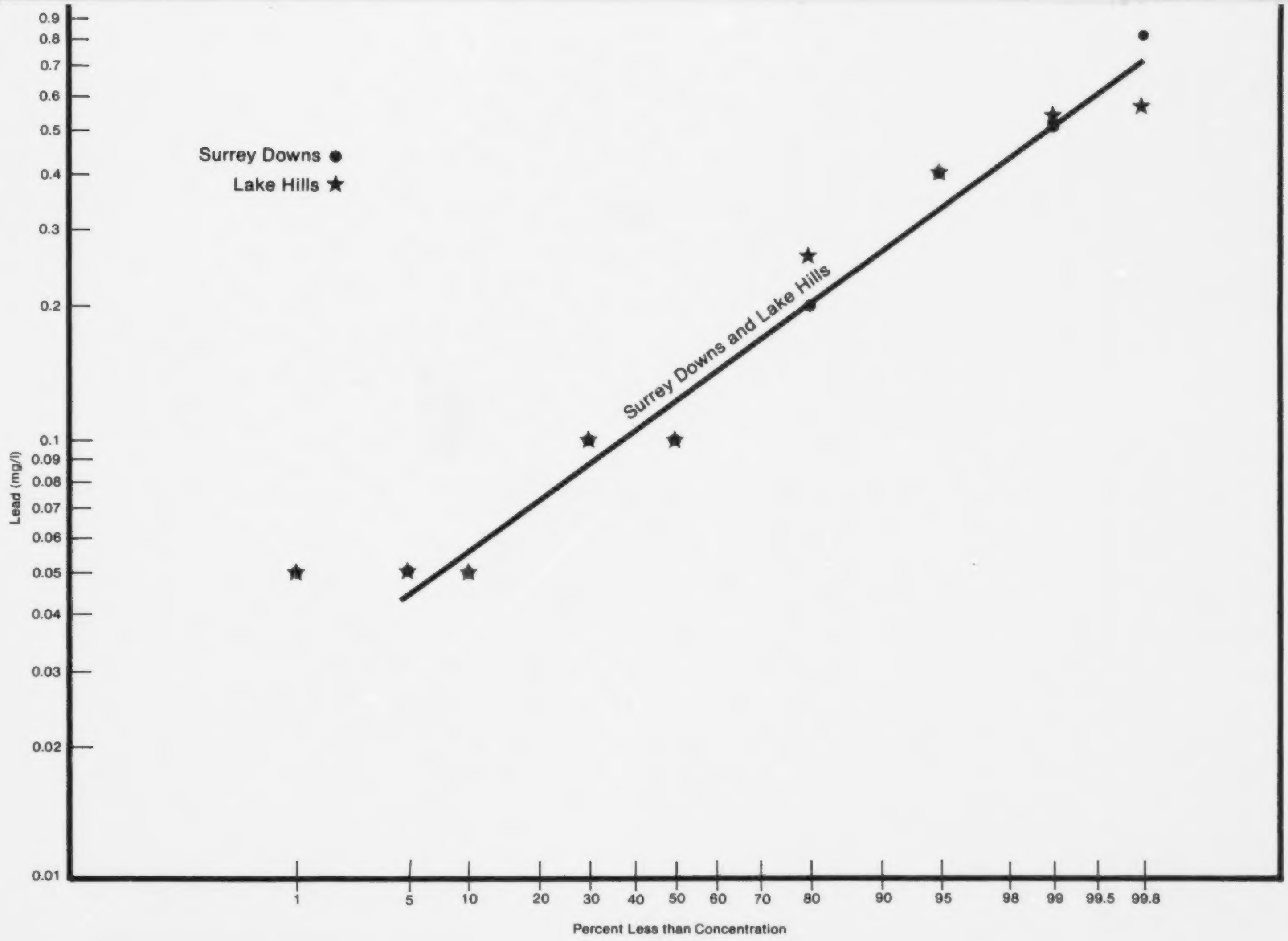


FIGURE A-24 Frequency Distribution of Lead Concentration

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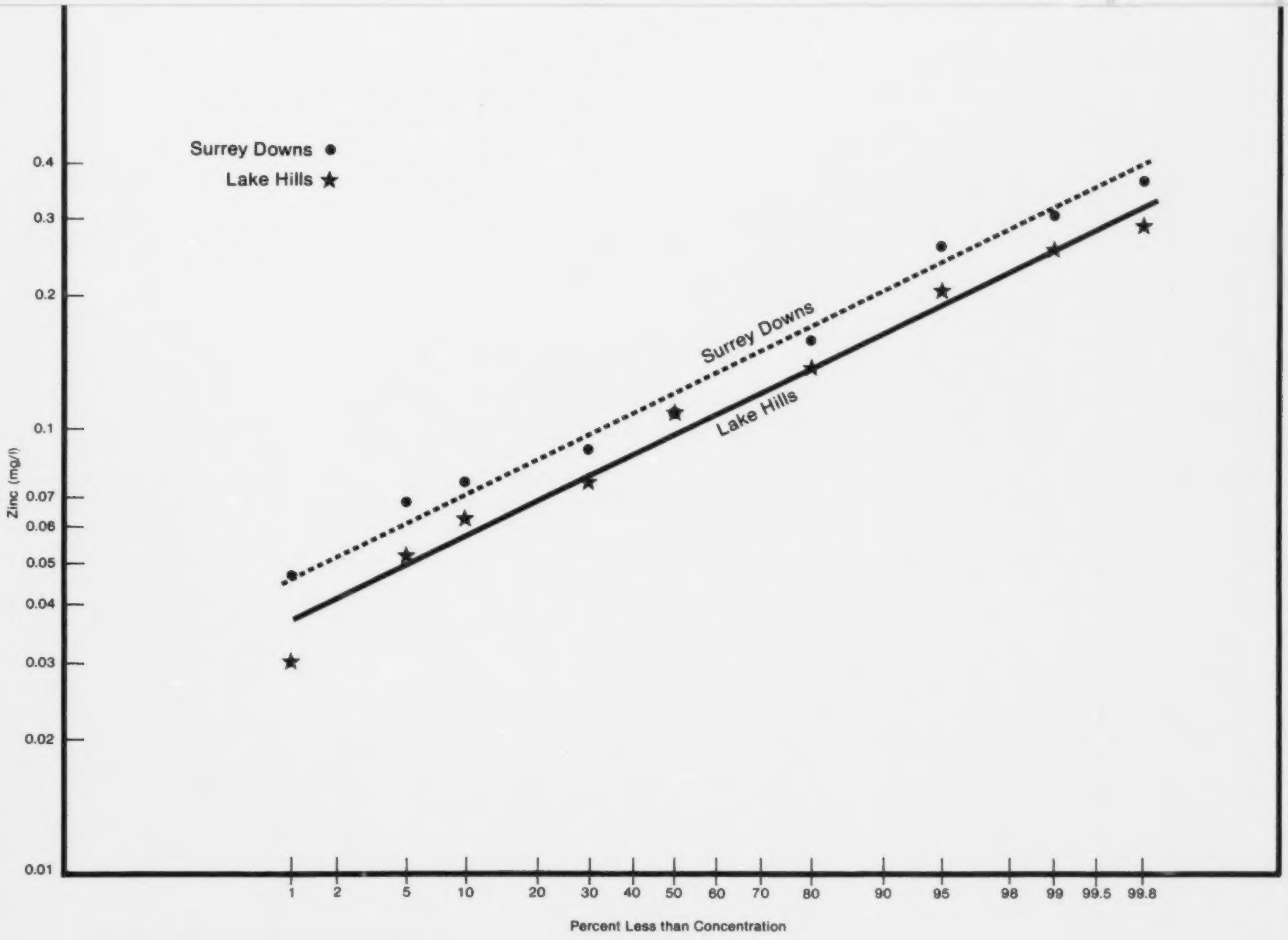

FIGURE A-25 Frequency Distribution of Zinc Concentration

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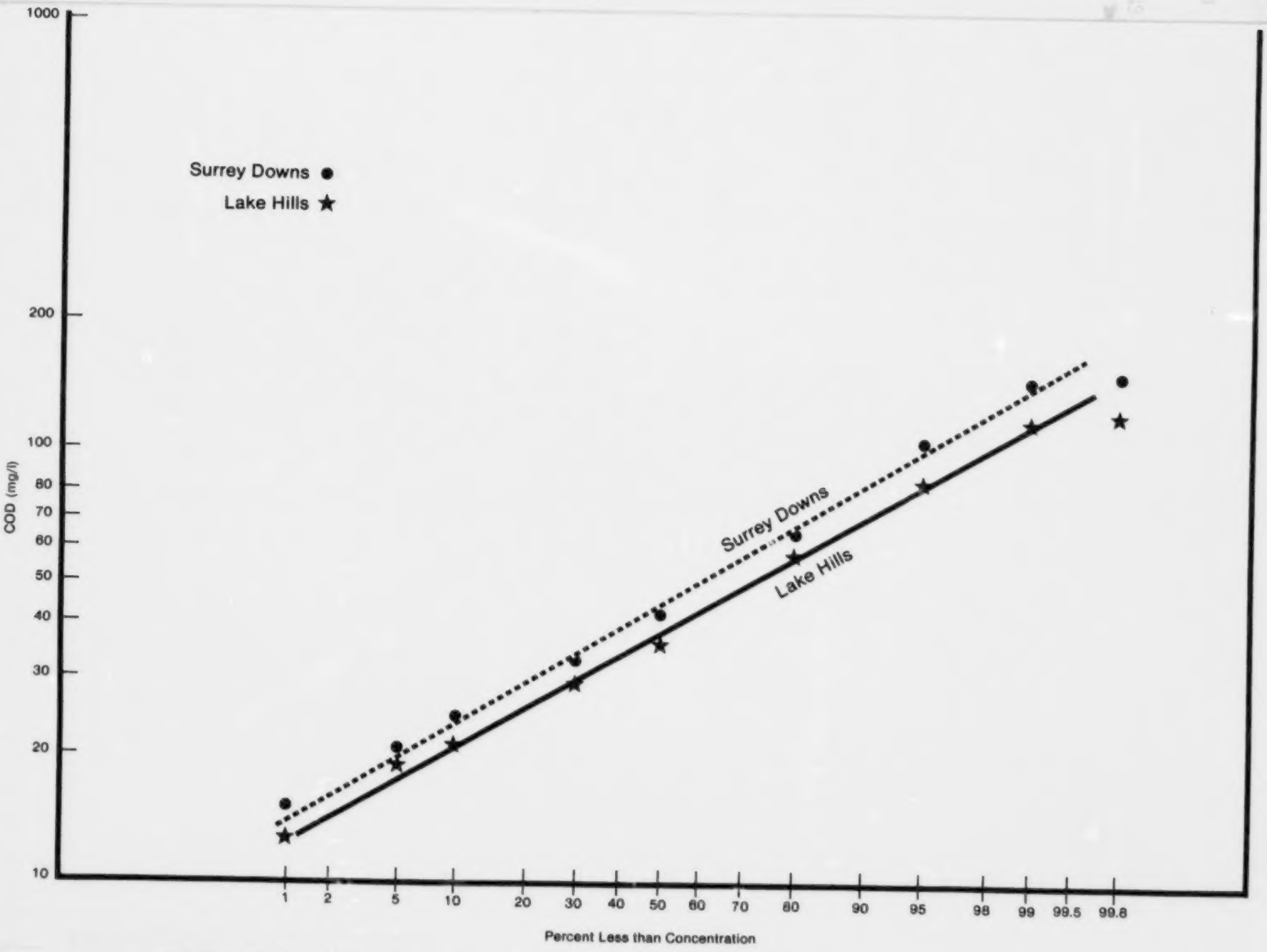

FIGURE A-26 Frequency Distribution of COD Concentration

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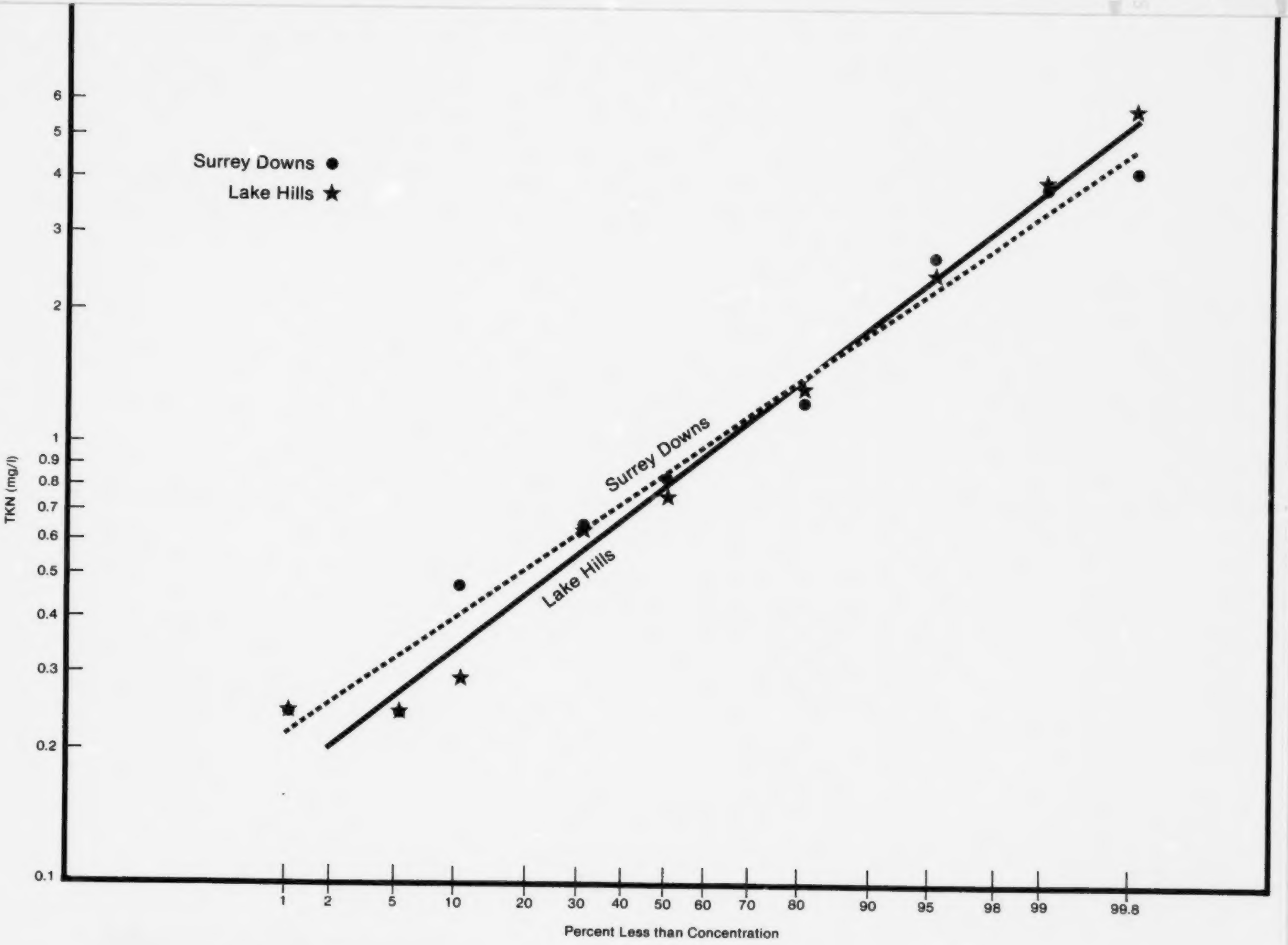

FIGURE A-27 Frequency Distribution of TKN Concentration

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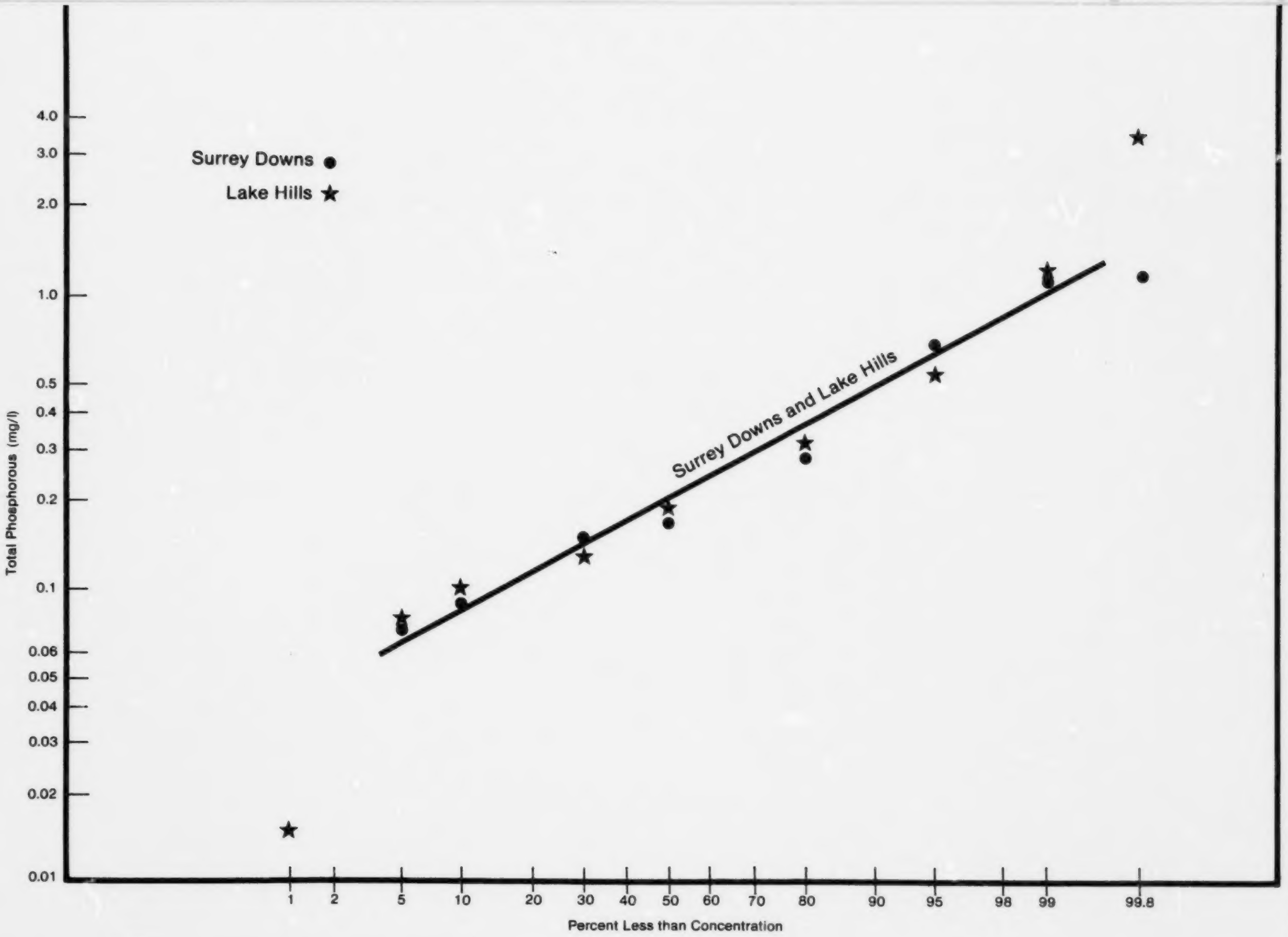

FIGURE A-28 Frequency Distribution of TP Concentration

EPA-287 (Cin.)
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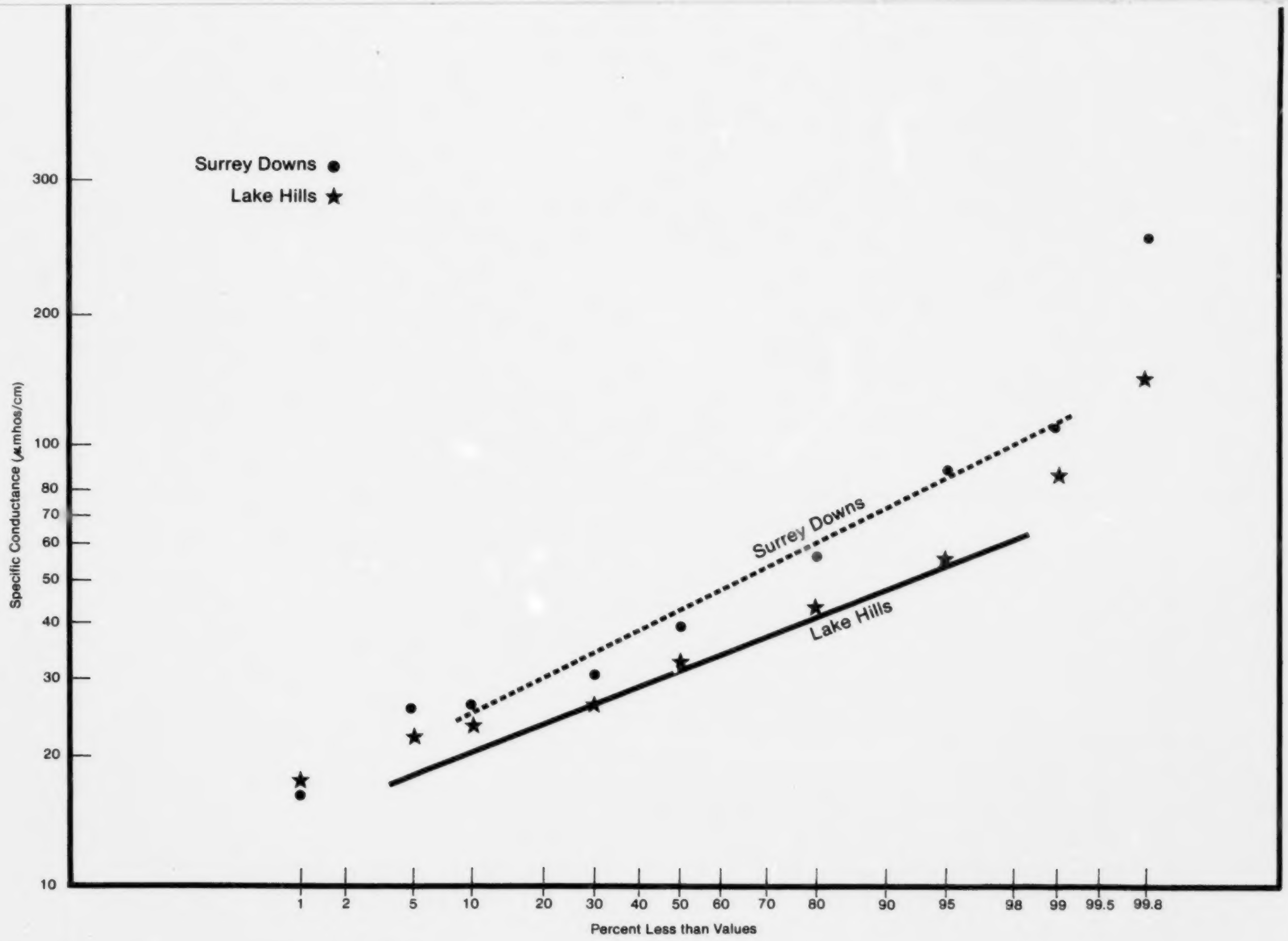

FIGURE A-29 Frequency Distribution of Specific Conductance Values

EPA-287 (Cin.)
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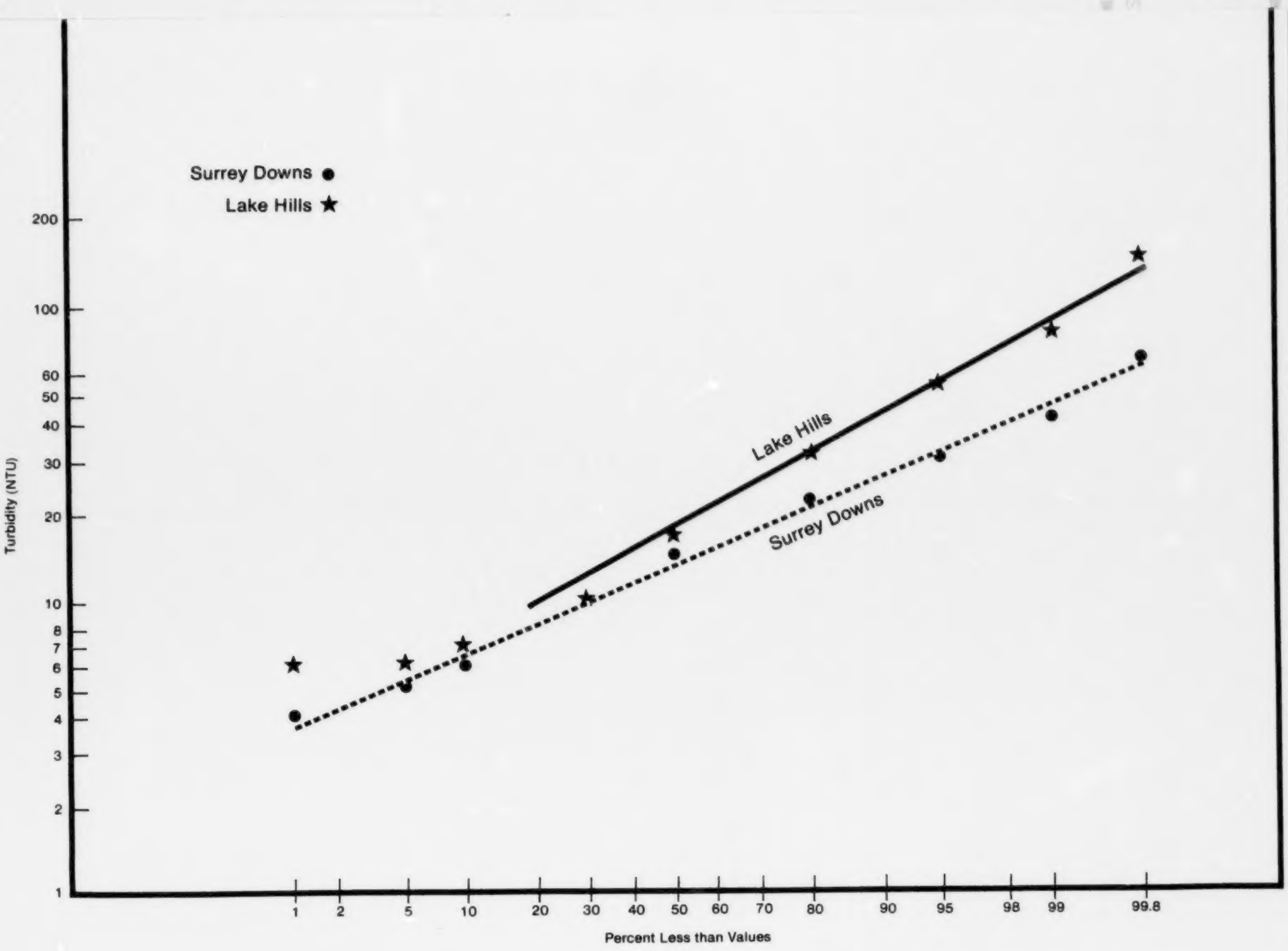

FIGURE A-30 Frequency Distribution of Turbidity Values

EPA-287 (Cin.)
(4-76)

FIGURE A-31

SURREY DOWNS TOTAL SOLIDS BY SEASON

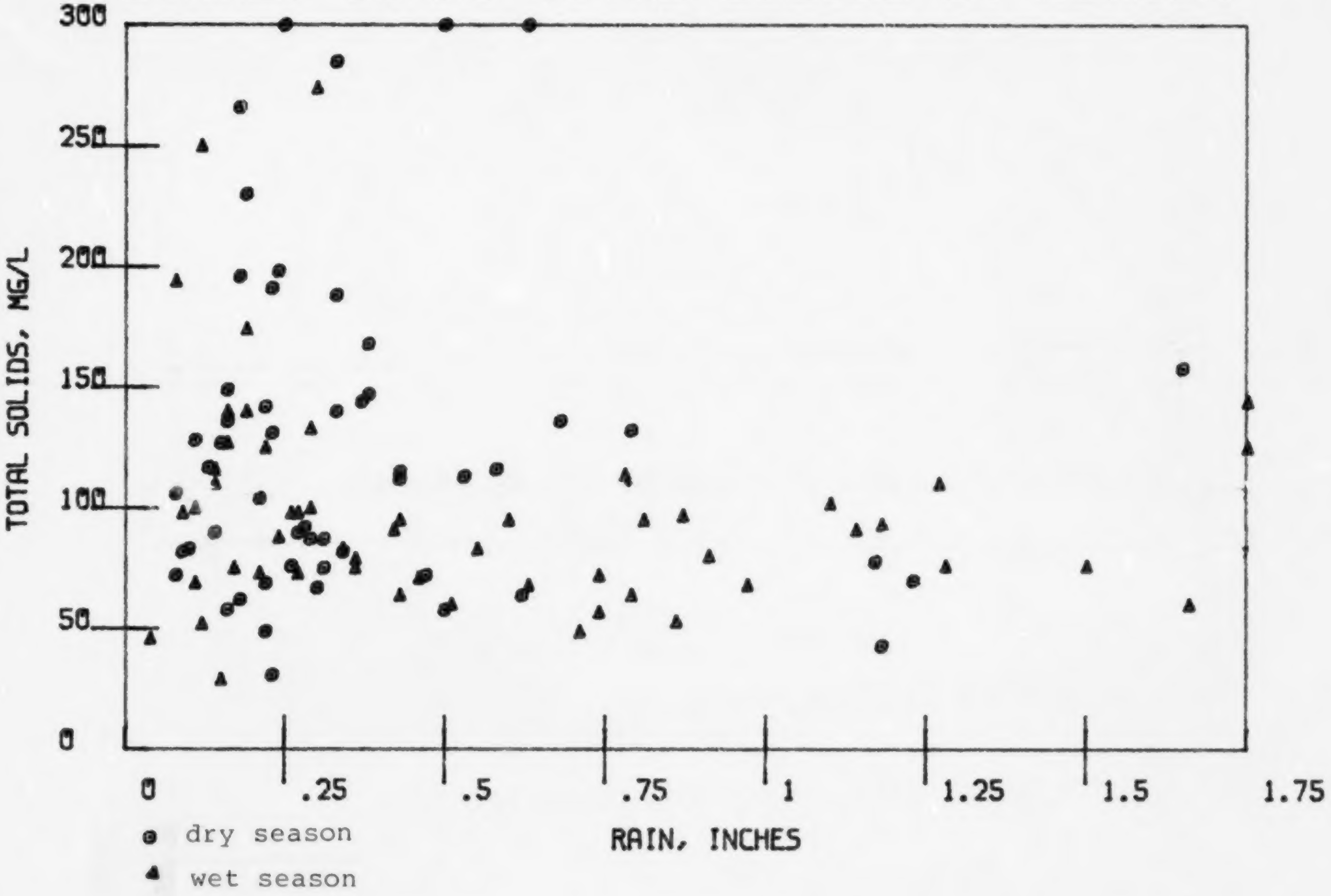

FIGURE A-32

SURREY DOWNS LEAD BY SEASON

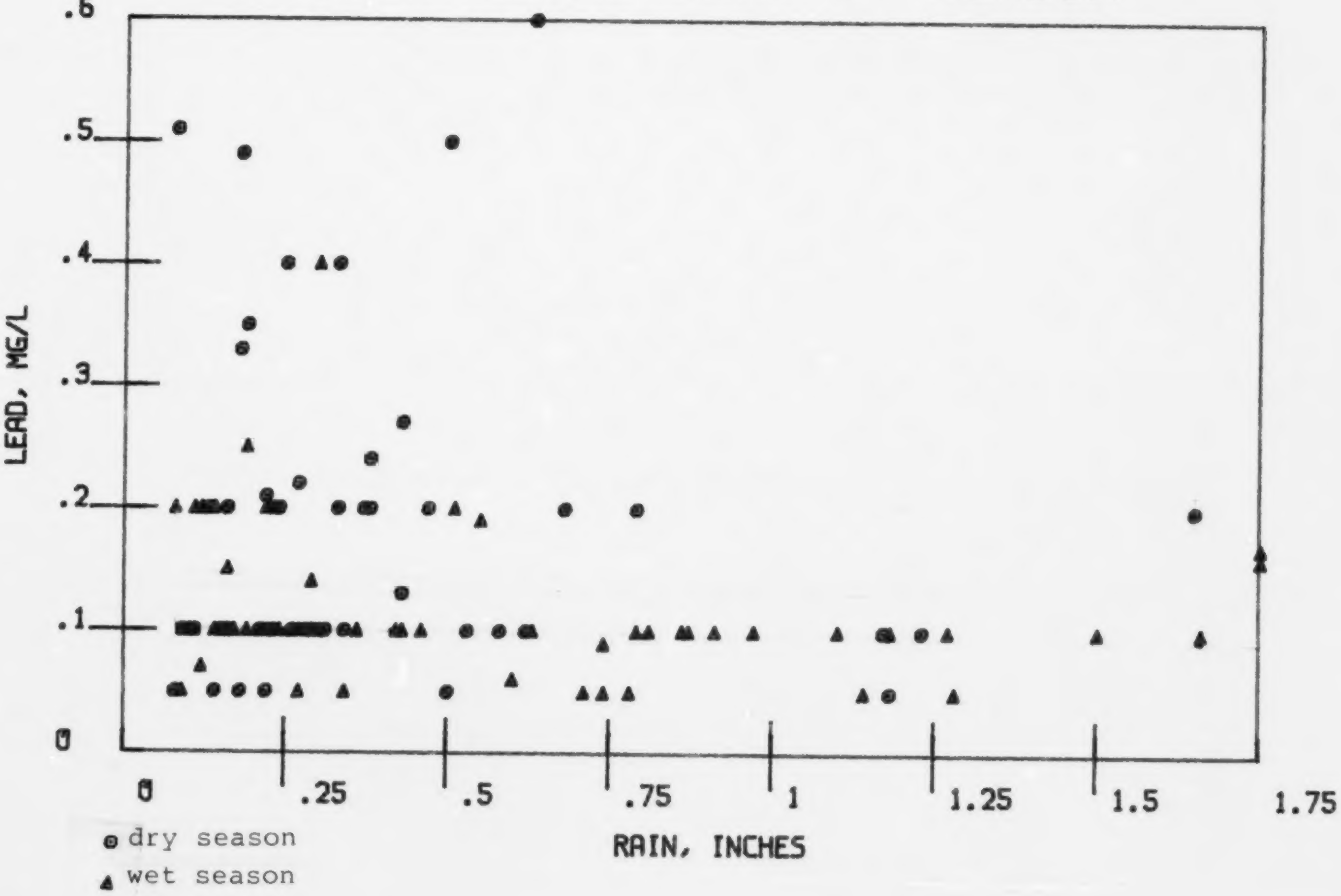

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FIGURE A-33

SURREY DOWNS ZINC BY SEASON

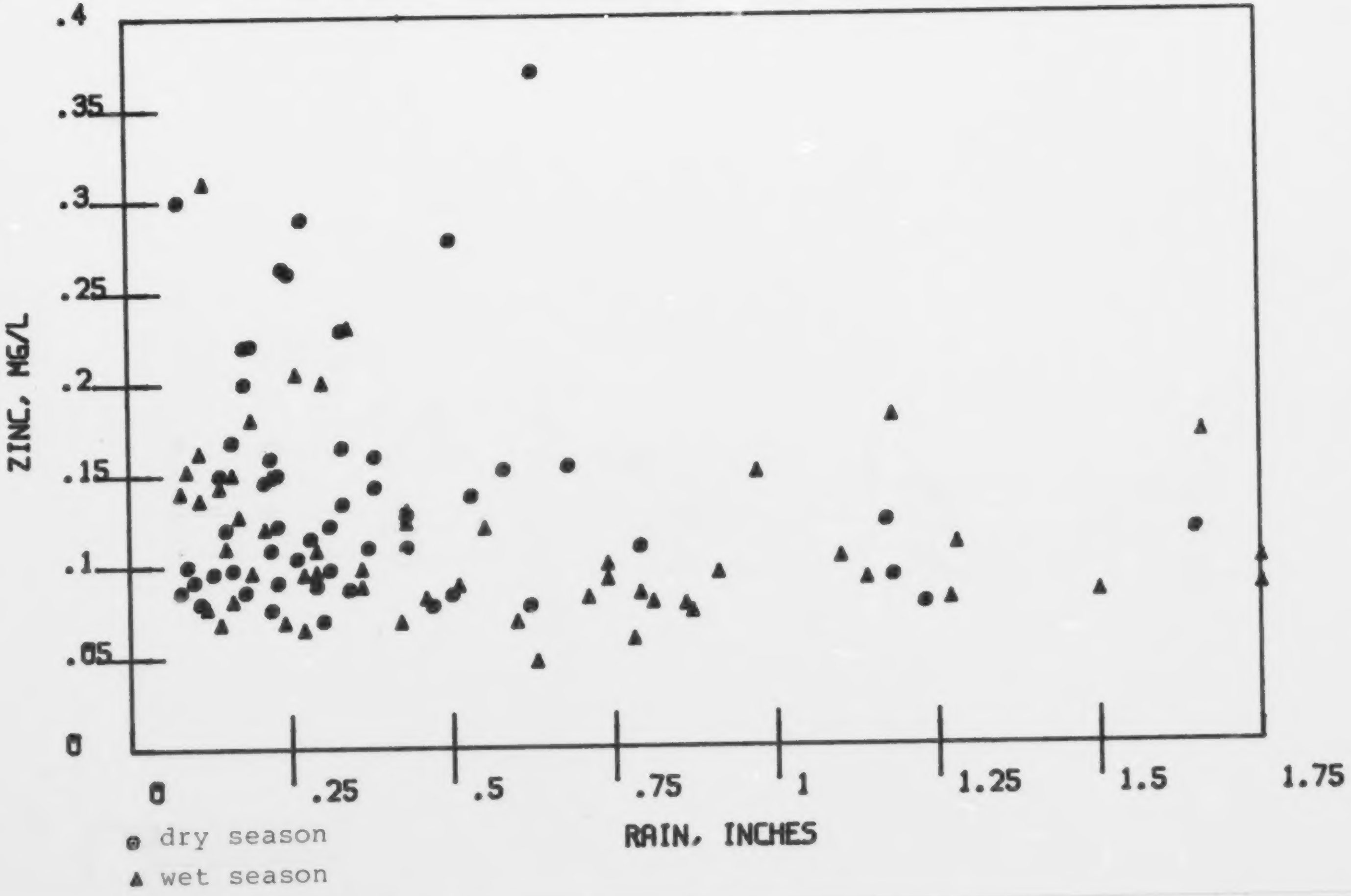

FIGURE A-34

SURREY DOWNS COD BY SEASON

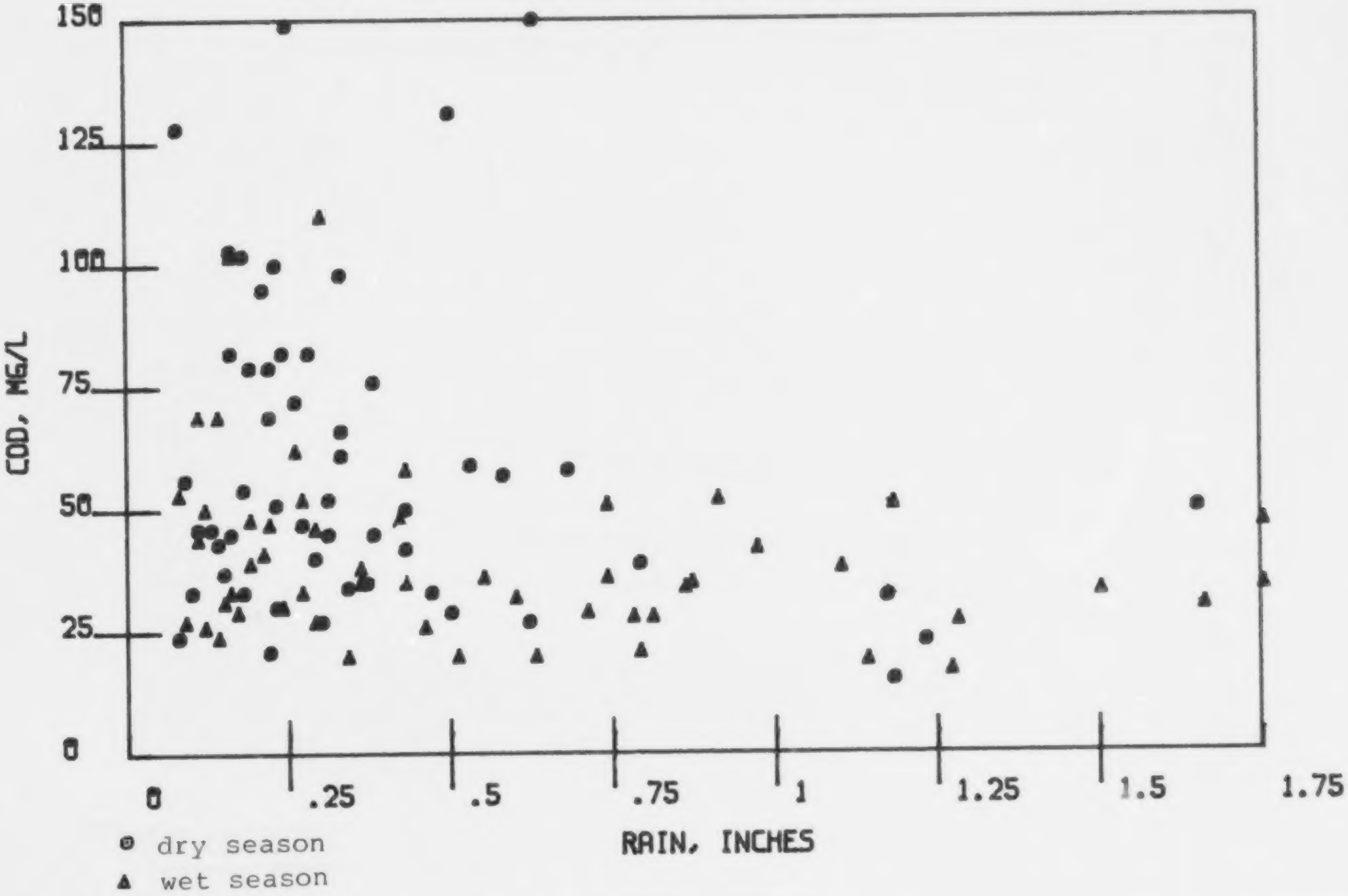

FIGURE A-35

SURREY DOWNS TKN BY SEASON

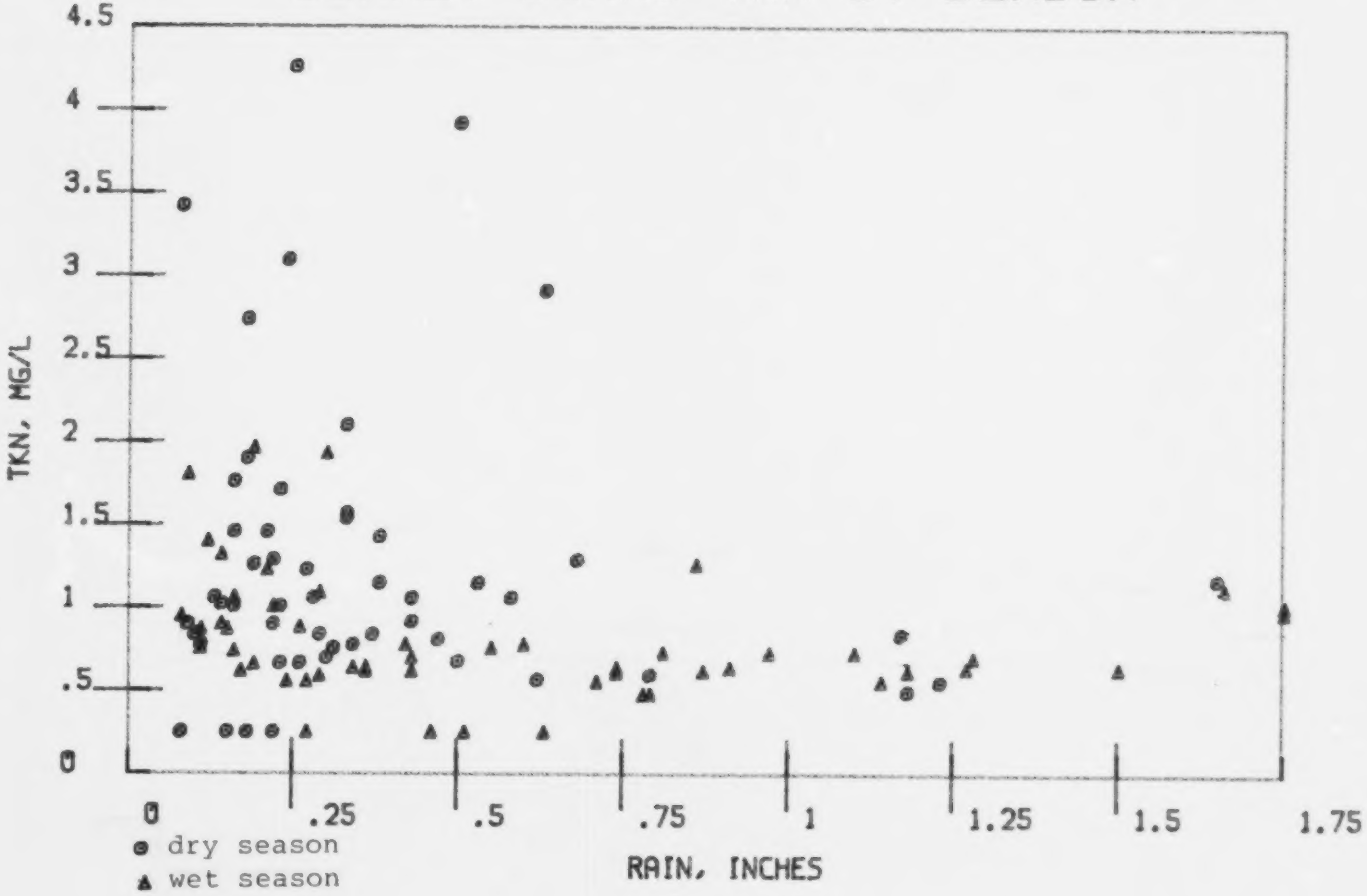

FIGURE A-36

SURREY DOWNS TOTAL PHOSPHOROUS BY SEASON

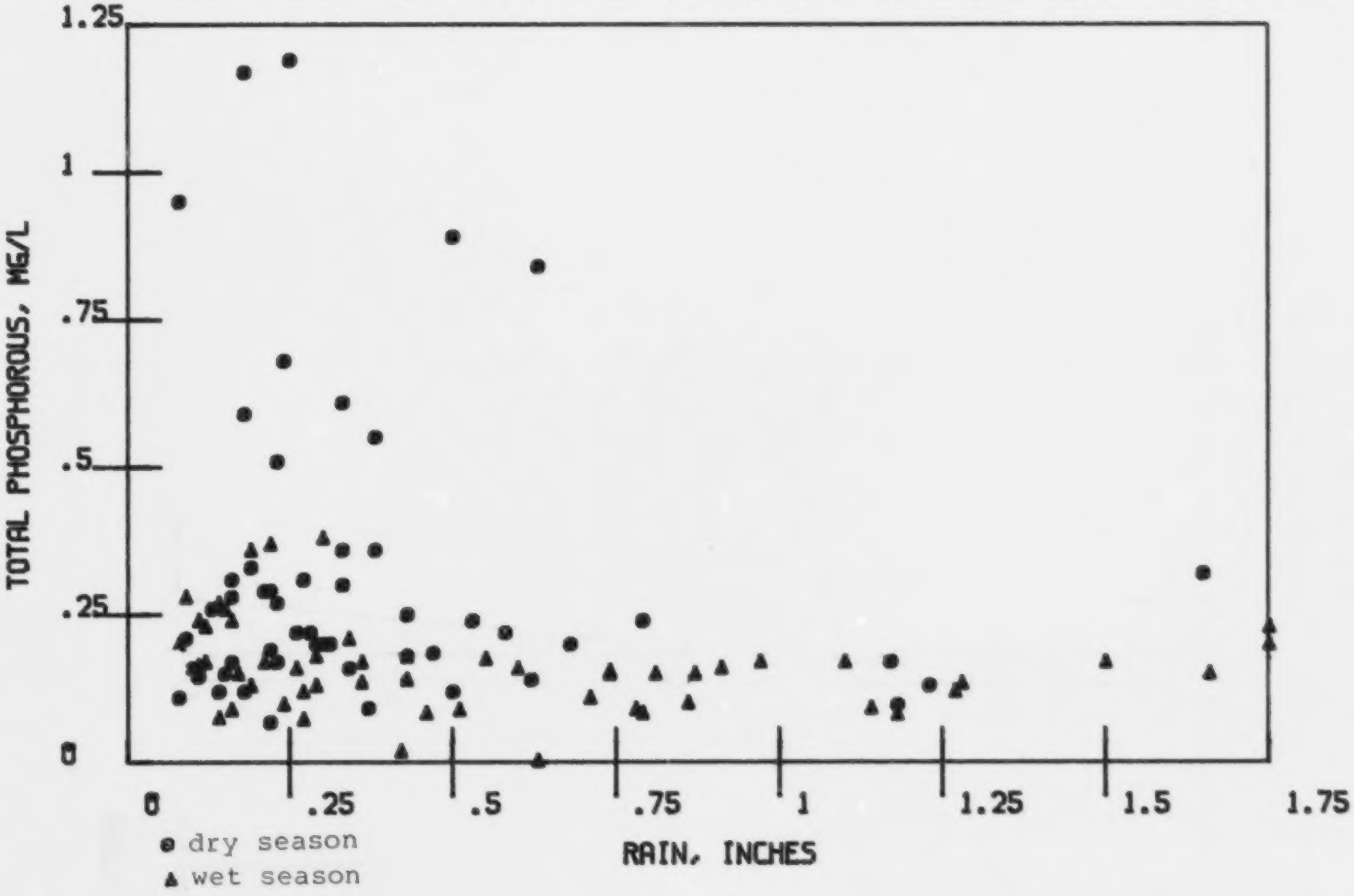

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FIGURE A-37

SURREY DOWNS PH BY SEASON

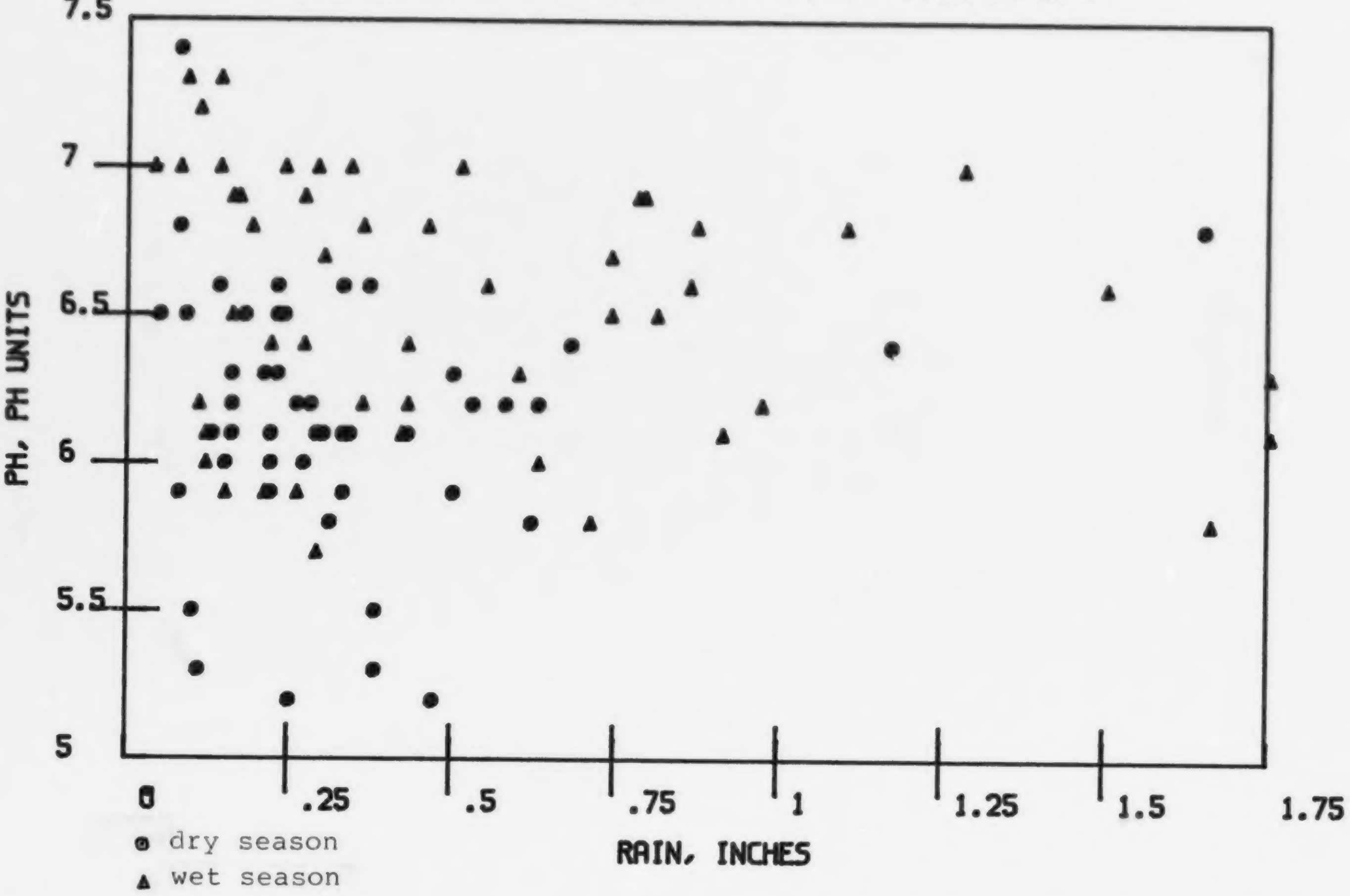

FIGURE A-38

SURREY DOWNS CONDUCTIVITY BY SEASON

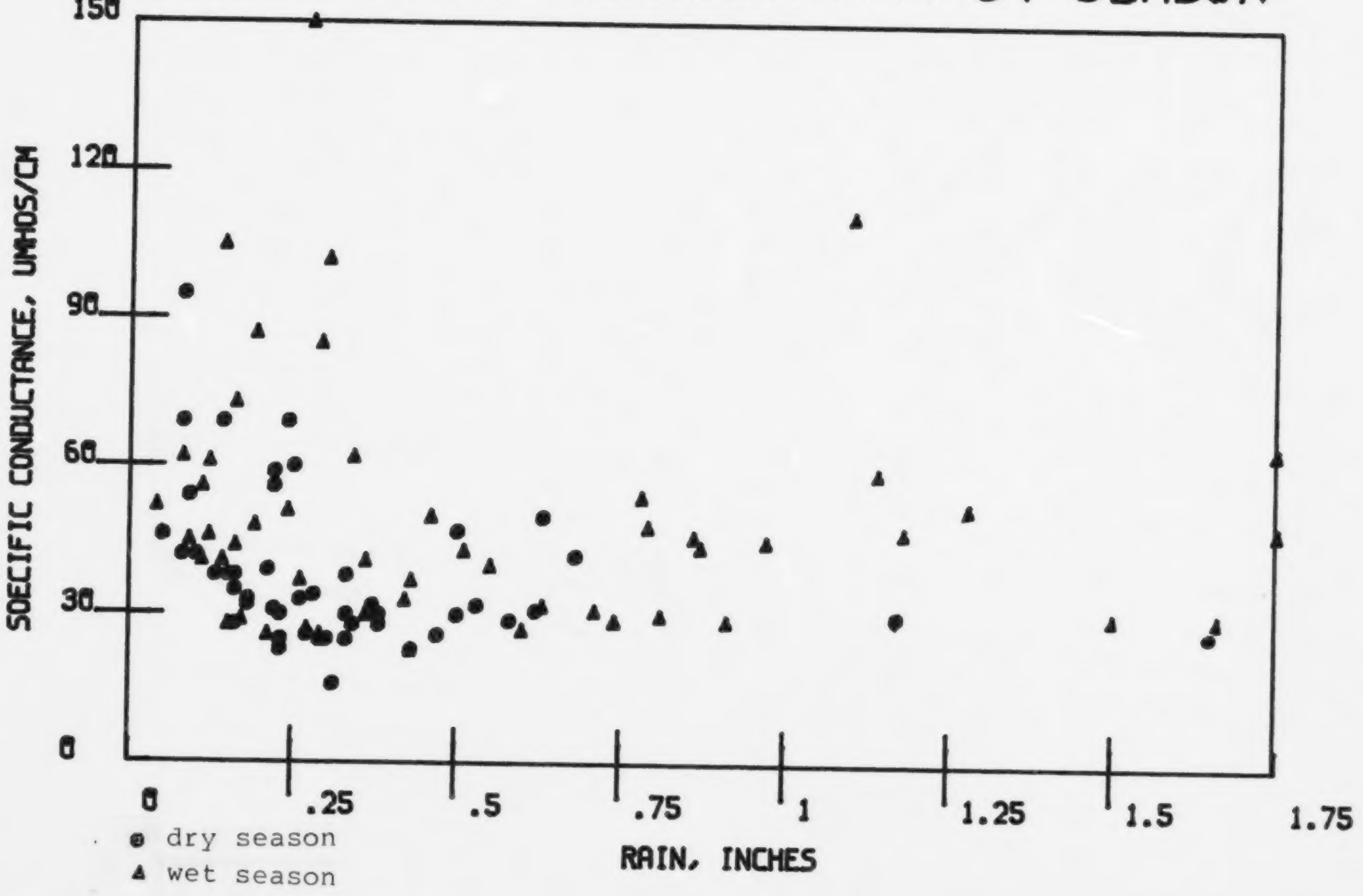

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FIGURE A-39

SURREY DOWNS TURBIDITY BY SEASON

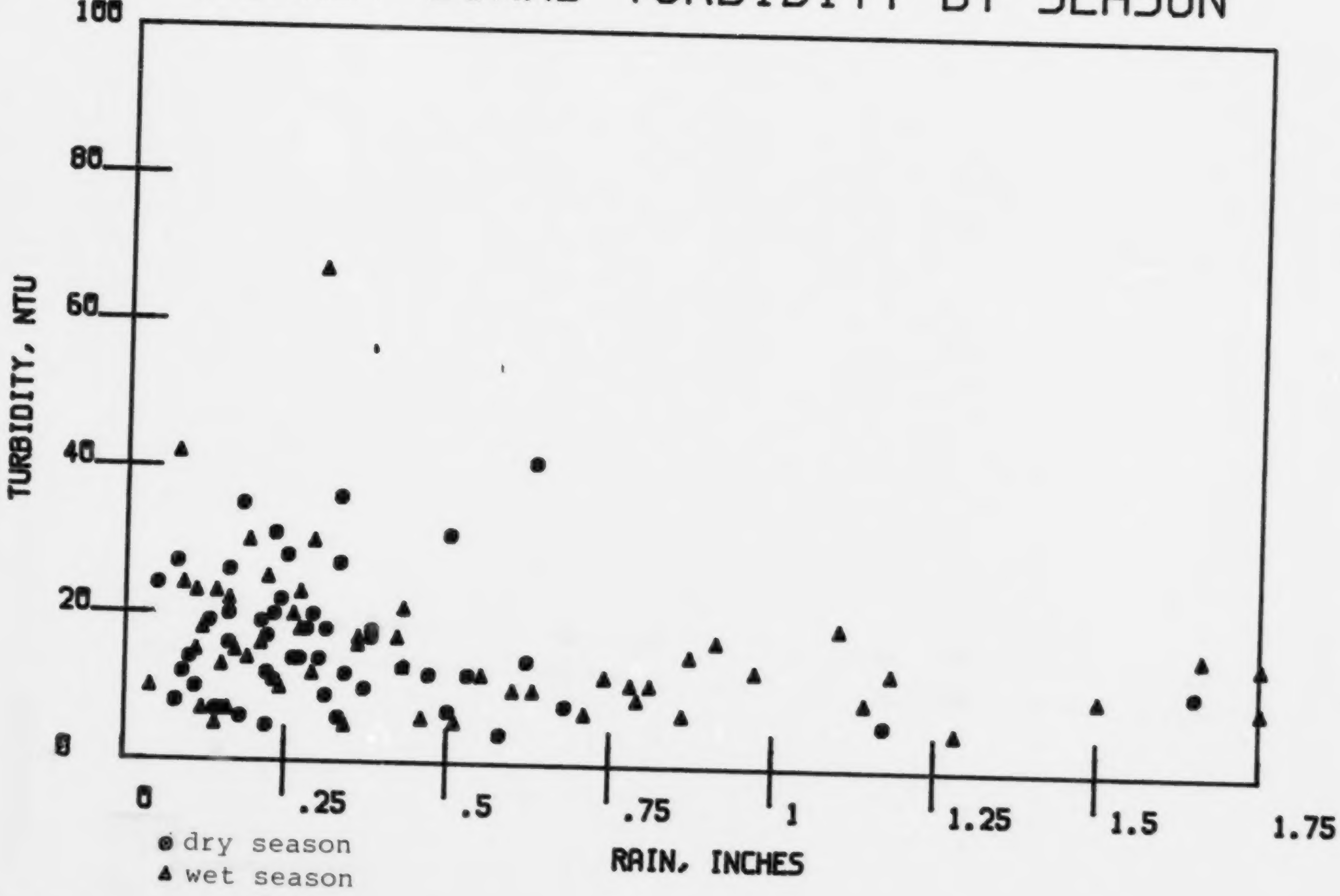

FIGURE A-40

LAKE HILLS TOTAL SOLIDS BY SEASON

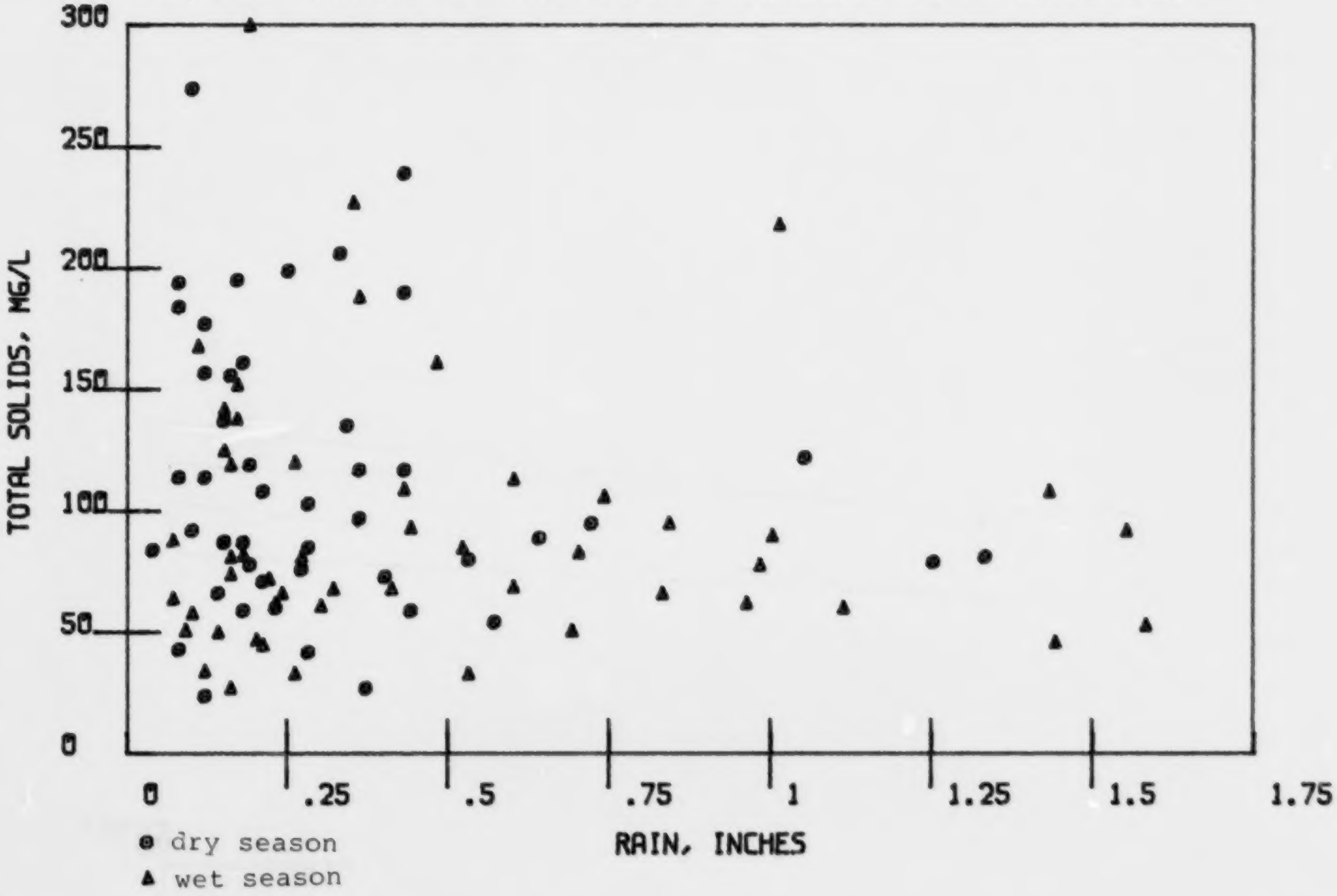

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FIGURE A-41

LAKE HILLS LEAD BY SEASON

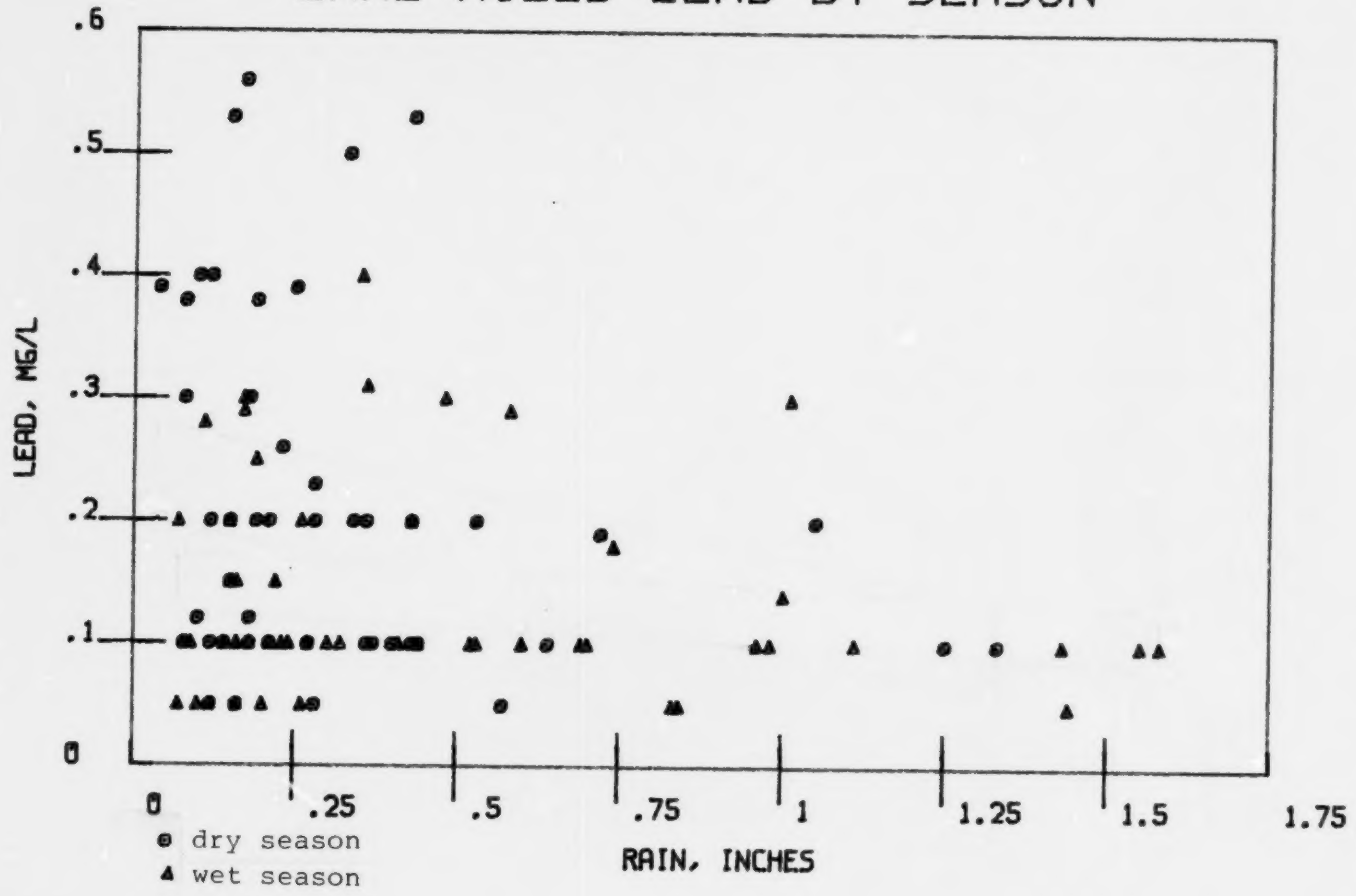

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FIGURE A-42

LAKE HILLS ZINC BY SEASON

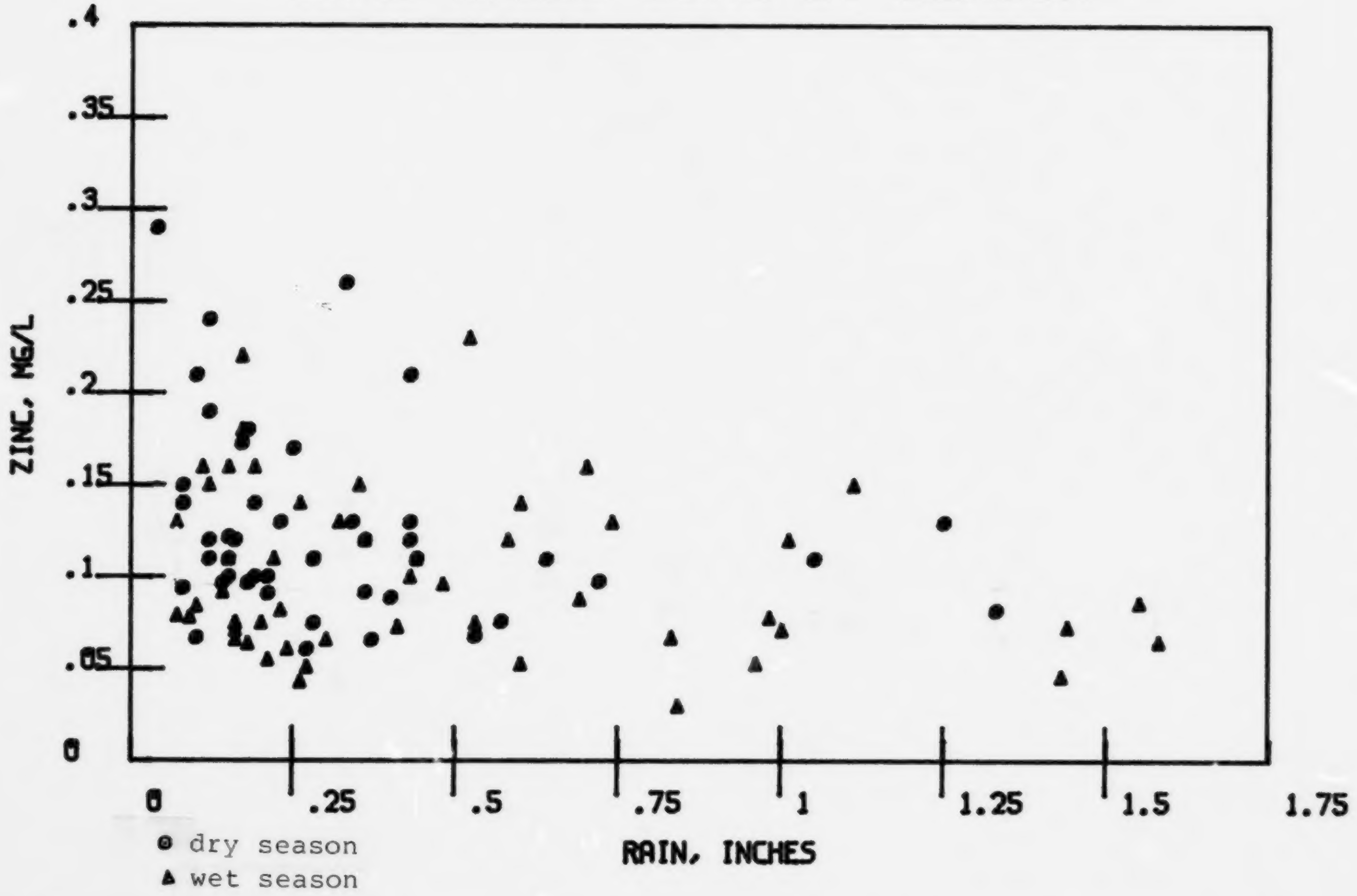

FIGURE A-43

LAKE HILLS COD BY SEASON

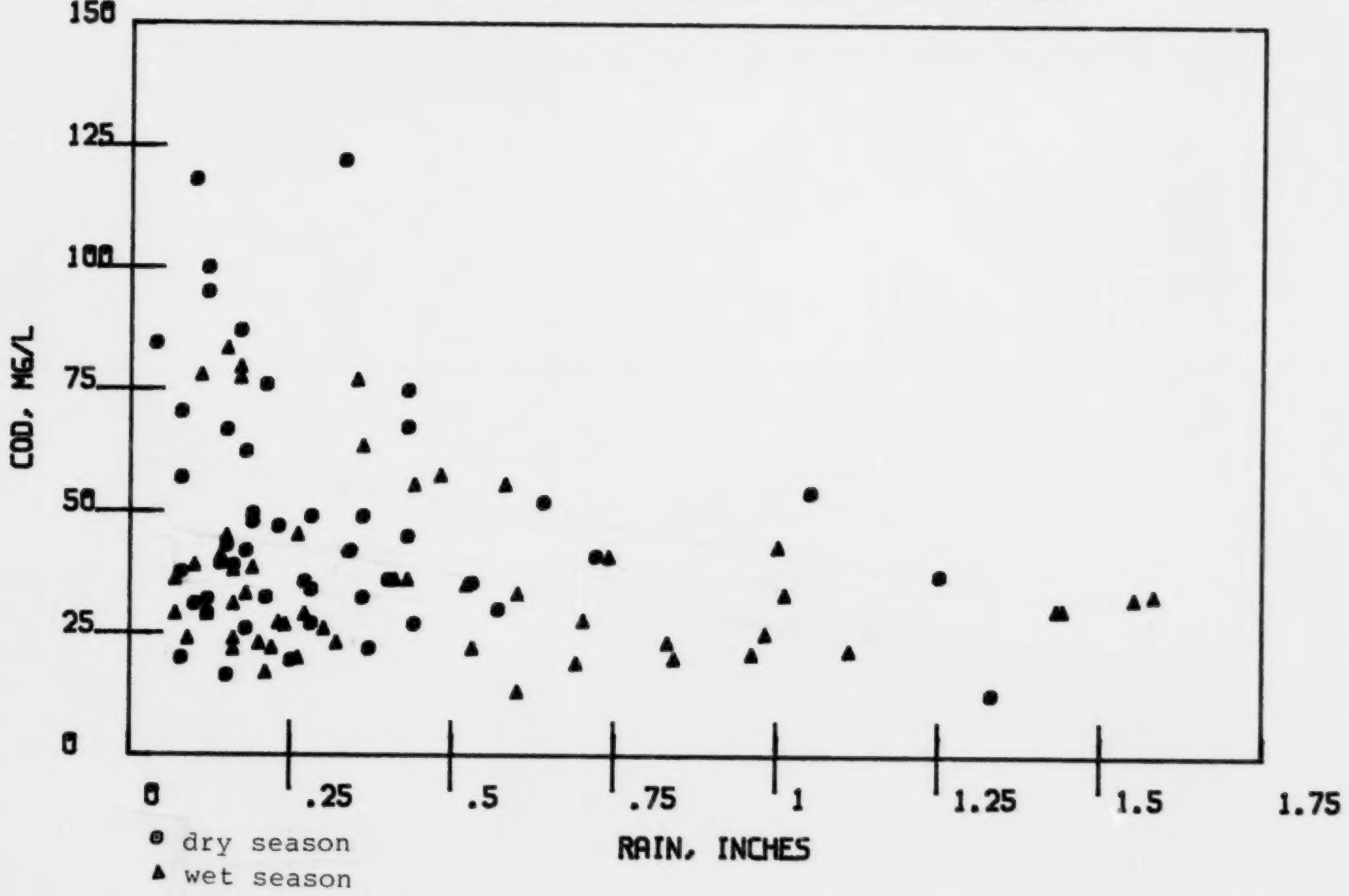

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FIGURE A-44

LAKE HILLS TKN BY SEASON

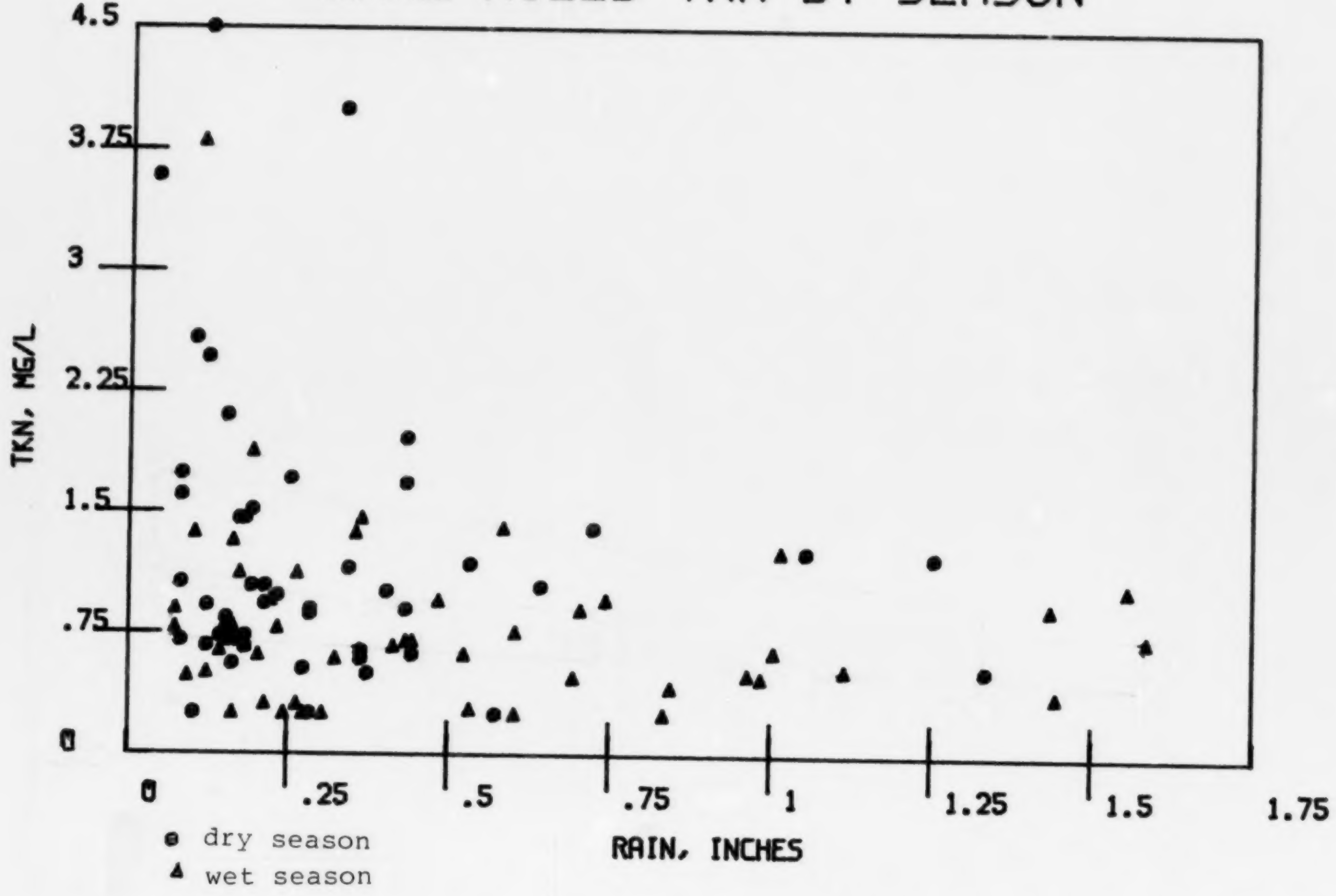

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FIGURE A-45

LAKE HILLS TOTAL PHOSPHOROUS BY SEASON

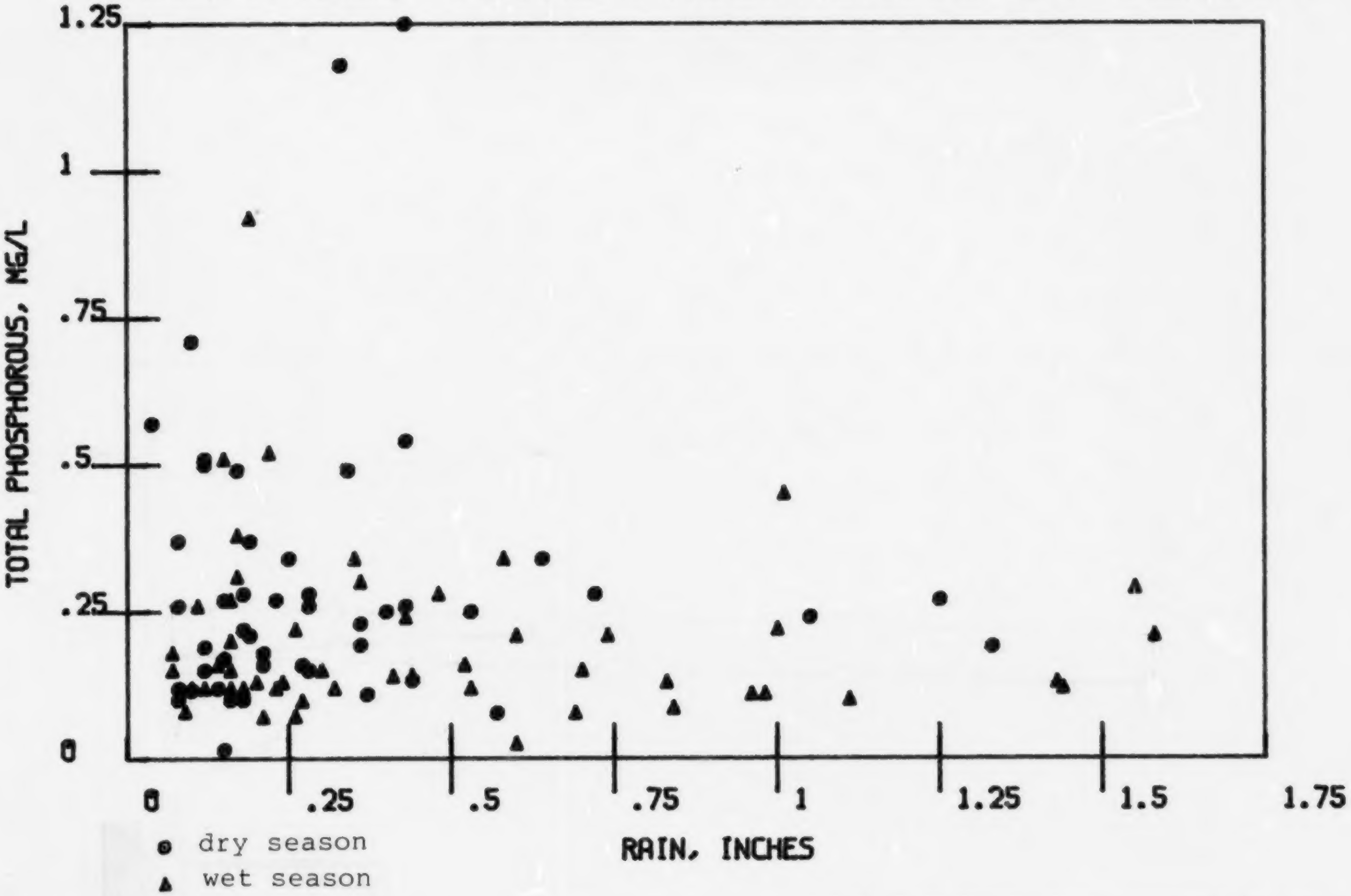

FIGURE A-46

LAKE HILLS PH BY SEASON

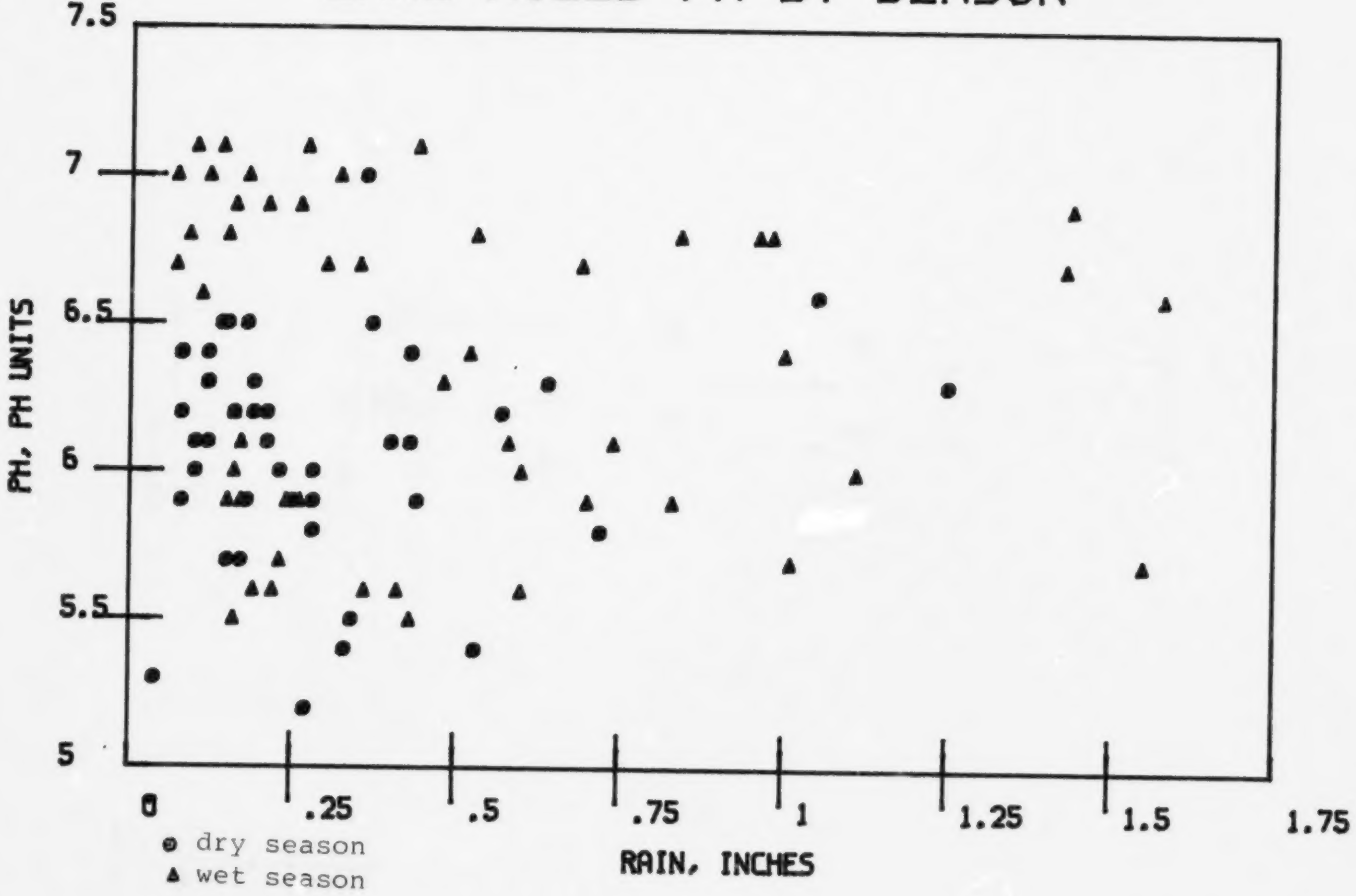

FIGURE A-47

LAKE HILLS CONDUCTIVITY BY SEASON

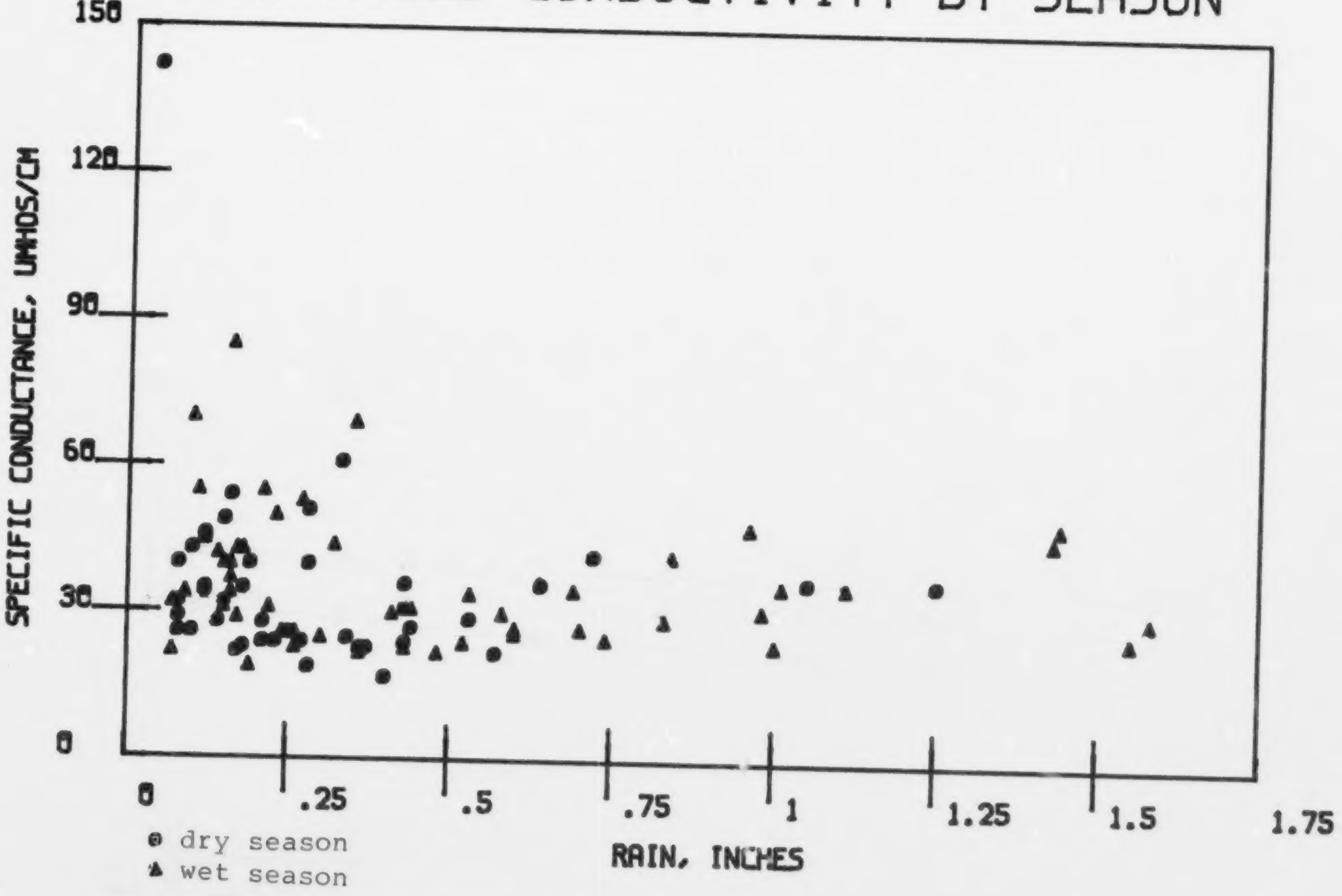

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FIGURE A-48

LAKE HILLS TURBIDITY BY SEASON

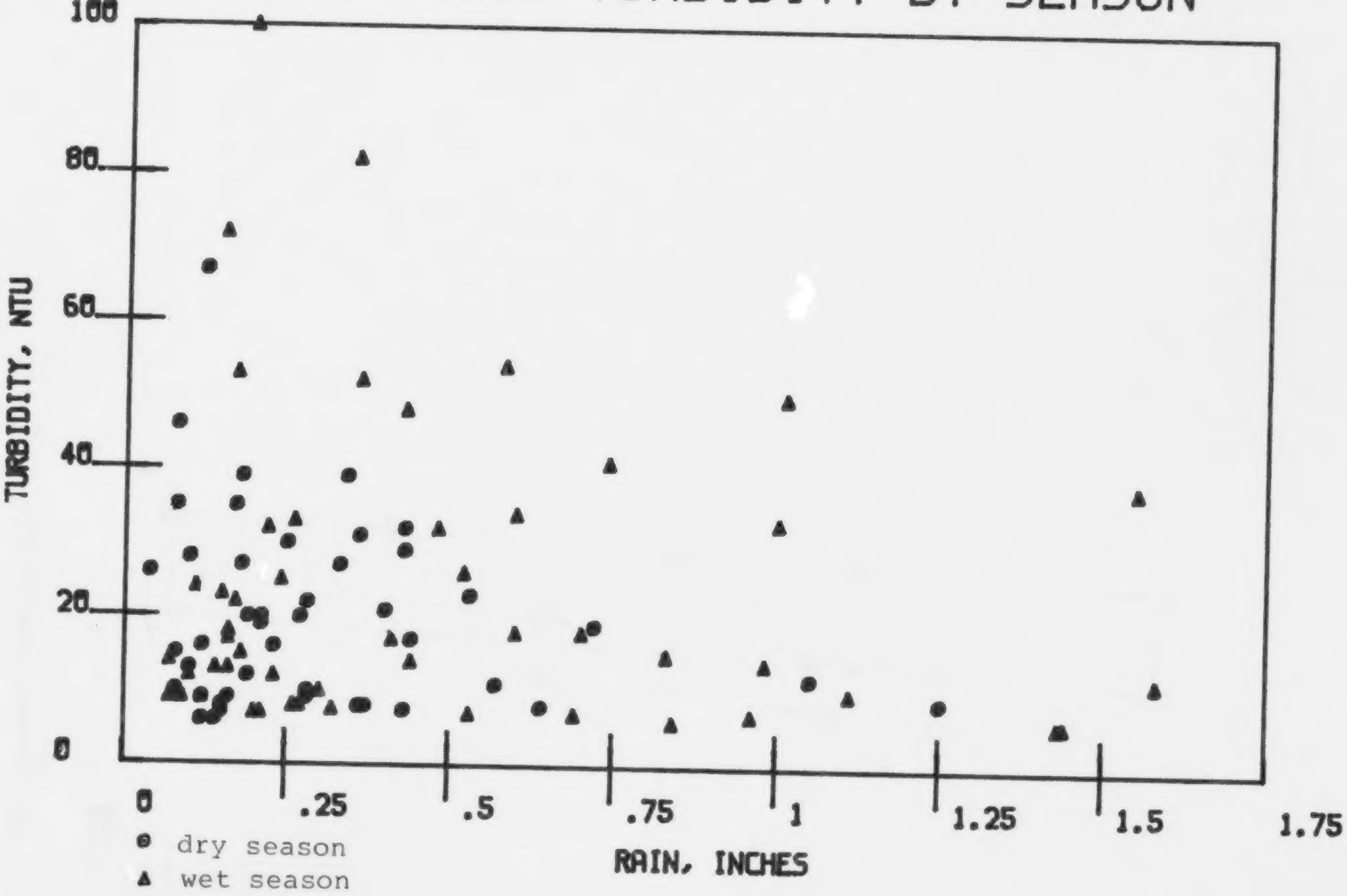

Table B-1. Surrey Downs Street Dirt Loadings
(Dry season, no street cleaning)

Sample Date	Sample Ident.	Days from last sign. rain	Days from last cleaning	Loading (lb/curb-mile)	Median size (microns)
7/15/80	A-112	4.9	4	261	363
7/18	A-115	6.9	7	268	327
7/22	A-119	11.0	11	423	385
7/25	A-122	14.0	14	329	347
7/28	A-126	17.0	17	304	321
7/31	A-129	20.1	20	384	289
8/4	A-131	24.0	24	299	361
8/7	A-133	26.1	27	364	363
8/12	A-138	32.0	32	383	333
8/15	A-140	34.2	35	395	456
8/19	A-144	1.3	39	298	420
8/22	A-148	4.4	42	356	407
8/25	A-152	7.4	45	408	381
8/29	A-155	1.1	49	485	424
9/4	A-157	2.5	53	219	547
9/9	A-161	2.7	58	313	457
9/16	A-165	9.4	>60	323	474
9/18	A-170	11.6	>60	312	463
9/23	A-174	2.0	>60	270	441
9/25	A-179	4.2	>60	384	473
9/30	A-185	.6	>60	233	599
3/4/81	A-312	.4	>60	382	752
3/10	A-319	6.3	>60	503	488
3/17	A-325	1.0	>60	442	934
3/19	A-329	2.9	>60	400	564
3/24	A-335	.8	>60	329	720
3/25	A-341	.4	>60	374	716
3/30	A-349	5.4	>60	405	968
4/1	A-353	7.4	>60	379	896
4/3	A-356	9.2	>60	372	782
4/6	A-362	12.4	>60	356	774
4/9	A-366	.8	>60	282	1006
4/13	A-372	1.7	>60	314	842
4/16	A-381	4.9	>60	597	514
4/20	A-386	8.9	>60	361	790
4/24	A-395	2.3	>60	341	850
4/27	A-400	5.3	>60	315	496
4/29	A-402	1.0	>60	594	936
5/4	A-418	.6	>60	422	832
5/6	A-429	2.6	>60	430	754
5/11	A-440	.4	>60	304	700
5/18	A-454	7.2	>60	343	800
5/20	A-459	1.0	>60	226	914
5/28	A-475	3.7	>60	443	580
6/2	A-481	7.5	>60	501	598
6/11	A-490	2.8	>60	432	748
6/16	A-494	3.6	>60	350	760
6/19	A-499	1.0	>60	279	872

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Table B-1. Surrey Downs Street Dirt Loadings(cont.)
(Dry season, no street cleaning)

Sample Date	Sample Ident.	Days from last sign. rain	Days from last cleaning	Loading (lb/curb-mile)	Median size (microns)
6/22	A-500	4.0	>60	368	732
6/25	A-508	7.0	>60	669	610
6/30	A-514	12.0	>60	409	494
7/2	A-520	1.6	>60	383	610
7/6	A-522	5.7	>60	562	611
7/9	A-525	2.2	>60	348	493
7/14	A-530	.9	>60	315	648
7/17	A-534	3.8	>60	540	559
7/20	A-538	7.0	>60	385	489
7/28	A-546	15.0	>60	446	484
8/4	A-548	22.0	>60	568	457
8/7	A-553	24.9	>60	500	454
8/12	A-555	29.9	>60	493	477
8/14	A-558	32.1	>60	416	520
8/18	A-559	35.8	>60	503	479
8/21	A-565	39.1	>60	516	445
8/25	A-567	43.1	>60	486	415
8/28	A-571	45.9	>60	546	421
9/2	A-575	1.5	>60	282	613
9/4	A-579	3.6	>60	498	468
9/8	A-581	8.4	>60	435	429
9/11	A-586	11.5	>60	450	444
9/14	A-588	14.4	>60	506	440
9/15	A-590	15.3	>60	275	443
9/18	A-593	18.4	>60	872	447
9/23	S-594	1.4	>60	277	682
Count		74.0	74	74	74
Average		10	>30	399	575
Minimum		.4	4	219	289
Maximum		45.9	>60	872	1006

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Table B-2. Surrey Downs Street Dirt Loadings
(Wet season, no street cleaning)

Sample Date	Sample Ident.	Days from last sign. rain	Loading (lb/curb-mile)	Median size (microns)
10/2/80	A-189	2.4	326	507
10/7	A-196	7.5	389	561
10/9	A-198	.9	406	442
10/14	A-206	6.1	336	500
10/16	A-208	8.2	339	408
10/21	A-213	13.2	371	963
10/23	A-218	15.2	342	514
10/28	A-221	20.1	369	444
10/30	A-227	22.2	379	450
11/18	A-236	8.8	244	1592
12/9	A-244	4.9	475	1228
1/6/81	A-249	5.3	346	1609
1/8	A-252	7.1	333	1600
1/13	A-259	12.3	406	870
1/15	A-263	14.3	371	888
1/20	A-267	19.1	447	1708
1/27	A-271	3.4	556	1220
1/29	A-276	.3	290	1064
2/5	A-284	7.1	681	802
2/10	A-289	12.3	471	724
2/17	A-291	.6	278	1190
2/19	A-295	2.7	330	930
2/26	A-304	1.1	425	888
Count		23.0	23	23
Average		8.5	387	917
Minimum		.3	244	408
Maximum		22.2	681	1708

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Table B-3. Surrey Downs Street Dirt Loadings
(Dry season, with street cleaning)

Sample Date	Sample Ident.	Days from last sign. rain	Days from last cleaning	Loading (lb/curb-mile)	Median size (microns)
4/2/80	S-17	6.4	2.0	529	359
4/2	S-18	6.4	.1	498	276
4/7	S-19	1.1	2.9	538	368
4/7	S-20	1.1	.1	545	303
4/11	S-21	1.6	1.9	695	429
4/11	S-22	1.6	.1	442	310
4/16	S-23	1.7	1.9	713	364
4/16	S-25	1.7	.1	412	415
4/18	S-26	3.7	1.9	326	456
4/18	S-27	3.7	.1	265	428
4/21	S-28	1.2	2.9	303	488
4/21	S-29	1.2	.1	317	471
4/23	S-32	3.2	1.9	295	415
4/23	S-34	3.2	.1	386	391
4/25	S-36	5.2	1.9	371	441
4/25	S-38	5.2	.1	323	391
4/30	S-39	2.2	1.9	424	408
4/30	S-41	2.2	.1	332	329
5/5	S-42	7.2	2.9	333	376
5/5	S-44	7.2	.1	353	346
5/7	S-45	9.2	1.9	406	357
5/7	S-47	9.2	.1	315	333
5/9	S-49	11.2	1.9	472	327
5/9	S-51	11.2	.1	423	309
5/12	S-52	14.2	2.9	437	361
5/12	S-54	14.2	.1	427	349
5/14	S-56	16.2	1.9	384	300
5/14	S-58	16.2	.1	444	325
5/16	S-59	18.2	1.9	290	341
5/16	S-61	18.2	.1	304	335
5/19	S-63	21.2	2.9	305	314
5/19	S-65	21.2	.1	375	365
5/23	S-66	2.1	1.9	257	372
5/30	S-68	3.6	1.9	235	391
5/30	S-70	3.6	.1	252	371
6/4	S-72	2.0	1.9	237	356
6/4	S-75	2.0	.1	245	324
6/11	S-76	9.0	1.9	281	308
6/11	S-78	9.0	.1	295	334
6/13	S-80	11.0	1.9	336	343
6/13	S-81	11.0	.1	352	341
6/16	S-84	14.0	2.9	352	386
6/16	S-86	14.0	.1	320	302
6/18	S-87	1.6	1.9	251	415
6/18	S-88	1.6	.1	249	366
6/20	S-90	3.6	1.9	328	368
6/20	S-92	3.6	.1	315	354
6/30	S-95	5.0	2.9	302	330

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Table B-3. Surrey Downs Street Dirt Loadings(cont.)
(Dry season, with street cleaning)

Sample Date	Sample Ident.	Days from last sign. rain	Days from last cleaning	Loading (lb/curb-mile)	Median size (microns)
6/30	S-97	5.0	.1	306	301
7/2	S-100	7.0	1.9	363	328
7/2	S-101	7.0	.1	364	282
7/7	S-103	12.0	4.9	296	322
7/7	S-105	12.0	.1	285	304
7/9	S-107	14.0	1.9	353	327
7/9	S-109	14.0	.1	345	339
9/24/81	S-598	2.6	1.0	253	531
9/29	S-599	.2	3.9	139	862
9/29	S-600	.4	.1	177	444
9/30	S-602	1.2	.9	164	734
9/30	S-603	1.4	.1	180	421
Count		60.0	60.0	60	60
Average		7	1.2	347	377
Minimum		.2	.1	139	276
Maximum		21.2	4.9	713	862

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Table B-4. Surrey Downs Street Dirt Loadings
(Wet season, with street cleaning)

Sample Date	Sample Ident.	Days from last sign. rain	Days from last cleaning	Loading (lb/curb-mile)	Median size (microns)
10/2/81	S-605	.4	1.9	136	751
10/2	S-606	.7	.2	195	459
10/5	S-607	3.4	3.0	228	361
10/9	S-610	.7	1.2	127	462
10/12	S-611	3.4	1.9	129	448
10/12	S-612	3.6	.1	122	383
10/16	S-613	7.4	1.9	204	316
10/16	S-616	7.7	.2	177	327
10/19	S-617	10.4	2.9	229	303
10/20	S-621	11.4	3.9	245	378
10/20	S-622	11.6	.1	193	338
10/21	S-623	12.4	.8	202	345
10/21	S-624	12.6	.1	158	274
10/23	S-625	14.4	1.9	160	355
10/26	S-626	17.6	2.9	193	438
11/2	S-629	5.3	2.9	122	491
11/2	S-630	5.5	.1	123	419
11/5	S-632	8.3	2.9	156	454
11/5	S-633	8.6	.1	180	410
11/6	S-635	9.3	.8	166	407
11/9	S-637	12.3	3.8	106	794
11/16	S-639	1.0	10.8	239	1831
11/16	S-640	1.2	.1	117	729
11/19	S-642	1.7	2.9	135	466
11/20	S-645	2.8	.9	116	563
11/24	S-646	1	3.9	78	775
11/24	S-648	1.2	.1	88	548
11/25	S-649	2.0	.8	92	575
12/4	S-651	2.2	.1	92	985
12/7	S-652	1.2	2.9	86	725
12/7	S-653	1.3	.1	94	528
12/11	S-657	.8	3.9	98	740
12/11	S-659	.9	.1	127	404
12/14	S-660	.7	2.9	101	539
12/14	S-661	.9	.1	108	489
12/16	S-662	.6	1.9	119	641
12/16	S-663	.8	.1	127	528
12/21	S-665	1.8	4.9	172	466
12/21	S-666	2.0	.1	178	475
12/23	S-667	3.8	1.9	167	572
12/23	S-668	4.0	.1	110	518
Count		41.0	41.0	41	41
Average		4.9	1.8	146	537
Minimum		.4	.1	78	274
Maximum		17.6	10.8	245	1831

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Table B-5. Surrey Downs - 108th St. Street Dirt Loadings
(Dry season, no street cleaning)

Sample Date	Sample Ident.	Days from last sign. rain	Loading (lb/curb-mile)	Median size (microns)
4/16/80	A-24	1.7	268	992
4/21	A-30	1.3	306	1161
4/23	A-33	3.3	303	1221
4/25	A-37	5.3	669	980
4/30	A-40	2.2	371	1317
5/5	A-43	7.3	281	1155
5/7	A-46	9.3	606	1074
5/9	A-50	11.3	330	1360
5/12	A-53	14.3	525	1193
5/14	A-57	16.3	280	1407
5/16	A-60	18.3	400	1516
5/19	A-64	21.3	252	1352
5/23	A-67	2.1	281	1416
5/30	A-69	3.8	262	1245
6/4	A-73	2.0	257	880
6/11	A-77	9.0	236	1108
6/13	A-82	11.1	262	1205
6/16	A-85	14.0	208	1151
6/20	A-91	3.7	224	1083
6/30	A-96	5.1	312	1087
7/2	A-102	7.2	256	1264
7/7	A-104	12.1	451	1384
7/9	A-108	14.1	353	1156
7/15	A-113	4.0	259	1188
7/18	A-116	7.0	467	1413
7/22	A-120	11	1336	1194
7/25	A-123	14.0	312	1403
7/28	A-127	17.0	757	1600
7/31	A-128	20.0	463	1441
8/7	A-134	26.9	384	1155
8/12	A-139	32.1	1049	1340
8/15	A-141	34.9	1106	1289
8/19	A-145	1.3	680	1467
8/22	A-149	4.4	627	1323
8/25	A-153	7.4	840	1518
9/4	A-158	2.6	622	1561
9/16	A-166	9.6	932	1684
9/18	A-171	11.6	682	1617
9/23	A-175	2.2	595	1518
9/25	A-180	4.2	674	1708
9/30	A-186	.6	591	1676
3/5/81	A-313	1.4	273	1246
3/10	A-320	6.3	509	978
3/17	A-326	1.2	394	1498
3/19	A-330	3.0	318	1312
3/25	A-339	.4	253	1460
3/30	A-350	5.5	265	1622
4/1	A-352	7.4	385	2182

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Table B-5. Surrey Downs - 108th St. Street Dirt Loadings
(Dry season, no street cleaning) (cont.)

Sample Date	Sample Ident.	Days from last sign. rain	Loading (lb/curb-mile)	Median size (microns)
4/6	A-360	12.3	323	1392
4/9	A-369	1.1	336	1582
4/13	A-374	1.8	238	956
4/15	A-379	3.9	209	1092
4/20	A-385	8.8	203	1410
4/24	A-397	2.4	314	1866
5/4	A-420	.8	331	1184
5/12	A-443	1.2	320	1320
5/20	A-457	1.0	252	1674
5/29	A-477	4.5	399	1450
6/2	A-482	7.6	368	1466
6/4	A-485	9.7	273	2040
6/16	A-495	3.7	506	1540
6/23	A-502	4.9	330	1996
6/26	A-510	7.8	308	1150
7/2	A-518	1.5	543	1286
7/6	A-521	5.7	240	992
7/9	A-526	2.4	311	1319
7/14	A-531	1.0	283	669
7/17	A-535	3.8	218	712
7/20	A-537	7.0	340	901
7/27	A-543	13.9	318	913
8/6	A-550	24.0	295	1163
8/18	A-561	36.1	557	1395
8/27	A-569	44.8	281	1503
9/2	A-574	1.4	199	1650
9/9	A-582	8.5	266	1412
9/15	A-589	14.3	300	1360
9/23	A-596	1.6	157	1240
Count		77.0	77	77
Average		8.7	409	1334
Minimum		.4	157	669
Maximum		44.8	1336	2182

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Table B-6. Surrey Downs - 108th St. Street Dirt Loadings
(Wet season, no street cleaning)

Sample Date	Sample Ident.	Days from last sign. rain	Loading (lb/curb-mile)	Median size (microns)
10/2/80	A-190	2.4	382	1730
10/7	A-197	7.6	378	1874
10/9	A-199	.9	432	1264
10/14	A-205	5.7	374	1548
10/16	A-209	7.9	400	1584
10/21	A-212	12.8	278	1990
10/23	A-217	14.9	239	1258
10/28	A-222	19.9	386	2156
10/30	A-226	21.9	453	1764
11/18	A-235	8.8	163	1916
1/8/81	A-253	7.1	243	1340
1/13	A-260	12.3	267	1034
1/15	A-262	14.3	288	1408
1/20	A-268	19.3	209	1318
1/27	A-272	3.4	175	1148
1/29	A-275	.3	138	890
2/5	A-283	7.1	308	1468
2/10	A-290	12.3	239	1328
2/17	A-292	.7	365	1096
2/19	A-296	2.7	300	956
2/26	A-303	1.1	255	1310
10/9	A-609	.6	153	808
10/19	A-618	10.6	205	981
11/5	A-634	8.5	472	1952
11/19	A-643	1.8	128	1344
11/24	A-647	1.1	128	1869
12/8	A-655	2.3	123	964
Count		27.0	27	27
Average		7.7	277	1418
Minimum		.3	123	808
Maximum		21.9	472	2156

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Table B-7. Surrey Downs - Westwood Homes Road Street Dirt **Loadings** (Dry season, no street cleaning)

Sample Date	Sample Ident.	Days from last sign. rain	Loading (lb/curb-mile)	Median size (microns)
6/4/80	A-74	2.0	394	491
6/13	A-83	11.1	454	582
7/9	A-110	14.2	351	339
7/18	A-117	7.0	721	697
7/25	A-124	14.0	710	402
7/31	A-130	20.1	637	410
8/7	A-135	27.0	417	376
8/15	A-142	34.9	509	425
8/22	A-150	4.4	261	284
9/4	A-159	2.6	336	431
9/16	A-167	9.6	266	421
9/23	A-176	2.2	232	652
3/5/81	A-314	1.4	266	634
3/19	A-331	3.0	462	482
3/25	A-340	.4	112	682
3/30	A-351	5.5	225	784
4/7	A-364	.8	420	776
4/13	A-375	1.9	200	904
4/24	A-398	2.4	258	1352
5/4	A-421	.8	184	836
5/29	A-478	4.7	195	967
6/2	A-483	7.6	313	645
6/17	A-498	4.6	109	694
6/24	A-506	6.0	143	497
7/2	A-519	1.5	282	2117
7/7	A-523	.4	211	1715
7/17	A-536	3.8	206	625
7/23	A-541	10.0	185	786
7/27	A-544	14.0	149	528
8/6	A-551	24.0	432	418
8/18	A-560	35.9	268	636
8/27	A-570	44.9	431	517
9/2	A-576	1.5	206	917
9/10	A-583	9.5	170	999
9/23	A-597	1.6	147	626
Count		35.0	35	35
Average		9.58	310	704
Minimum		.4	109	284
Maximum		44.9	721	2117

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Table B-8. Surrey Downs - Westwood Homes Road Street Dirt Loadings (Wet season, no street cleaning)

Sample Date	Sample Ident.	Days from last sign. rain	Loading (lb/curb-mile)	Median size (microns)
10/2/80	A-191	2.5	517	422
10/9	A-200	.9	538	1084
10/14	A-207	5.9	318	866
10/21	A-214	12.9	270	934
10/28	A-223	19.9	519	674
11/18	A-237	8.6	906	>6370
1/8/81	A-254	7.2	125	990
1/15	A-264	14.4	462	1898
1/20	A-269	19.3	206	>6370
1/27	A-273	3.5	229	2858
2/5	A-285	7.3	515	1216
2/20	A-298	3.6	240	1142
2/26	A-305	1.2	229	1146
10/19	A-619	10.6	368	349
11/6	A-636	9.5	283	595
11/19	A-644	1.8	241	1543
12/8	A-656	2.3	182	1789
Count		17.0	17	17
Average		7.7	362	>1200
Minimum		.9	125	0
Maximum		19.9	906	>6370

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Table B-9. Lake Hills Street Dirt Loadings
(Dry season, no street cleaning)

Sample Date	Sample Ident.	Days from last sign. rain	Loading (lb/curb-mile)	Median size (microns)
4/22/80	A-31	2.3	434	734
4/24	A-35	4.3	444	749
5/7	A-48	17.3	705	573
5/14	A-55	24.3	671	626
5/16	A-62	26.3	467	679
6/3	A-71	1.4	451	710
6/12	A-79	10.3	544	525
6/19	A-89	2.7	721	494
6/24	A-93	7.7	552	637
7/1	A-99	6.0	774	419
7/8	A-106	13.0	577	583
7/10	A-111	15.2	664	492
7/17	A-114	5.7	558	556
7/22	A-118	10.6	673	472
7/25	A-121	13.6	920	413
7/28	A-125	16.6	858	430
7/31	A-245(?)	19.7	731	434
8/6	A-132	24.7	627	416
8/8	A-136	26.7	758	382
8/12	A-137	30.6	801	392
8/15	A-143	33.8	711	386
8/19	A-146	1.3	552	402
8/22	A-147	4.3	497	529
8/25	A-151	6.3	478	434
8/29	A-154	1.1	350	588
9/4	A-156	1.3	386	592
9/9	A-160	2.4	428	607
7/7/81	A-524	.4	156	384
7/10	A-528	3.4	138	310
7/14	A-529	.9	132	464
7/16	A-533	3.0	196	346
7/21	A-539	8.2	261	323
7/27	A-542	14.0	331	335
8/4	A-547	22.0	302	393
8/7	A-552	24.8	297	377
8/12	A-554	29.8	273	327
8/14	A-557	31.8	243	404
8/19	A-562	36.8	219	511
8/21	A-564	39.0	299	386
8/25	A-566	43.0	241	407
8/28	A-572	46.1	326	388
9/2	A-573	1.3	157	530
9/4	A-578	3.6	235	380
9/8	A-580	7.4	271	362
9/11	A-585	10.4	271	355
9/14	A-587	13.4	287	381
9/18	A-592	17.4	350	364
9/23	A-595	1.5	207	525
9/29	A-601	.5	206	599
Count		49.0	49	49
Average		14	443	472
Minimum		.4	132	310
Maximum		46.1	920	749

Table B-10. Lake Hills Street Dirt Loadings
(Wet season, no street cleaning)

Sample Date	Sample Ident.	Days from last sign. rain	Loading (lb/curb-mile)	Median size (microns)
10/9/81	A-608	.6	233	450
10/16	A-614	7.5	218	480
10/19	A-620	10.7	241	406
10/26	A-627	17.6	319	451
11/4	A-631	7.5	249	1012
11/16	A-641	1.6	338	1190
11/25	A-650a	2.0	201	1010
12/1	A-650	9.1	344	1840
12/8	A-654	2.0	238	3690
12/11	A-658	.9	257	1742
1/14/82	A-670	3.0	1065	1606
Count		11.0	11	11
Average		5.7	337	1262
Minimum		.6	201	406
Maximum		17.6	1065	3690

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Table B-11. Lake Hills Street Dirt Loadings
(Dry season, with street cleaning)

Sample Date	Sample Ident.	Days from last sign. rain	Days from last cleaning	Loading (lb/curb-mile)	Median size (microns)
9/15/80	S-164	8.6	.0	331	354
9/17	S-168	10.3	1.8	380	474
9/17	S-169	10.6	.0	330	305
9/22	S-172	1.1	2.9	238	371
9/22	S-173	1.4	.1	240	369
9/24	S-177	3.1	1.5	295	372
9/24	S-178	3.3	.1	267	279
9/26	S-181	5.1	.8	292	285
9/26	S-182	5.2	.2	270	282
9/29	S-183	8.1	2.9	265	320
9/29	S-184	8.3	.0	311	324
3/2/81	S-308	5.6	2.9	233	257
3/2	S-309	5.8	.1	213	237
3/4	S-310	.5	1.8	125	484
3/4	S-311	.6	.1	172	308
3/6	S-315	2.4	1.8	197	276
3/6	S-316	2.6	.1	207	241
3/9	S-317	5.4	2.9	228	266
3/9	S-318	5.6	.1	211	243
3/11	S-321	7.4	1.9	246	225
3/11	S-322	7.6	.1	201	238
3/13	S-323	9.4	1.8	235	247
3/16	S-324	.5	.1	150	300
3/18	S-327	2.3	1.9	185	290
3/18	S-328	2.5	.1	168	241
3/20	S-332	4.3	1.9	223	246
3/20	S-333	4.5	.1	233	210
3/24	S-334	.8	3.8	374	335
3/24	S-336	1.0	.1	144	237
3/25	S-337	.2	.9	134	550
3/25	S-338	.3	.1	143	293
3/27	S-344	2.2	1.9	167	260
3/27	S-346	2.4	.1	166	232
3/30	S-347	5.2	2.9	267	321
3/30	S-348	5.3	.1	141	454
4/3	S-355	.3	2.9	159	329
4/3	S-357	.5	.1	136	284
4/6	S-359	3.3	2.9	159	334
4/6	S-361	3.5	.1	156	303
4/9	S-365	.7	2.9	111	415
4/9	S-367	.9	.0	130	343
4/10	S-370	1.7	.9	135	329
4/13	S-371	1.4	2.9	164	390
4/13	S-376	1.6	.0	170	301
4/15	S-377	3.4	1.9	195	312
4/15	S-378	3.6	.0	156	263
4/17	S-382	5.4	1.9	211	262
4/17	S-384	5.6	.1	211	263

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Table B-11. Lake Hills Street Dirt Loadings (cont.)
(Dry season, with street cleaning)

4/21	S-387	9.4	3.9	109	484
4/21	S-388	9.6	.1	125	301
4/23	S-389	.9	1.9	117	352
4/23	S-391	1.1	.1	115	327
4/24	S-394	1.9	.9	110	364
4/24	S-396	2.1	.1	154	308
4/27	S-399	4.9	2.9	159	301
4/29	S-401	.9	1.9	103	450
4/29	S-403	1.1	.1	109	348
5/1	S-412	2.9	1.9	130	315
5/1	S-415	3.2	.2	107	260
5/4	S-417	.5	2.9	62	376
5/4	S-419	.7	.1	175	288
5/6	S-428	2.5	1.9	227	368
5/6	S-430	2.7	.1	184	240
5/8	S-433	.5	1.9	132	396
5/8	S-437	.7	.1	134	284
5/12	S-442	1.2	3.9	158	275
5/12	S-444	1.4	.1	155	270
5/13	S-445	1.2	.9	176	236
5/13	S-447	1.4	.0	189	265
5/15	S-449	4.2	1.9	99	324
5/15	S-451	4.4	.1	122	256
5/18	S-453	7.2	2.9	161	376
5/21	S-460	1.9	2.9	123	400
5/21	S-461	2.0	.0	128	326
5/22	S-462	2.7	.7	115	306
5/22	S-468	2.9	.1	133	262
5/29	S-476	4.5	6.9	188	340
6/1	S-479	6.5	9.9	198	282
6/1	S-480	6.7	.0	209	324
6/4	S-484	9.5	2.9	88	474
6/5	S-486	10.5	3.9	130	365
6/5	S-488	10.7	.1	125	294
6/11	S-489	2.9	1.9	290	465
6/11	S-491	3.1	.1	174	304
6/15	S-493	2.4	2.9	237	285
6/17	S-496	4.4	1.9	156	276
6/17	S-497	4.6	.0	265	332
6/23	S-501	4.8	5.9	205	422
6/23	S-503	5.0	.0	165	280
6/24	S-504	5.8	.9	210	346
6/24	S-505	6.0	.1	202	240
6/26	S-509	7.8	1.9	167	289
6/26	S-511	8.0	.0	158	291
6/29	S-512	10.8	2.9	201	319
6/29	S-513	11.0	.0	196	298
7/1	S-515	.4	1.9	111	402
7/1	S-516	.6	.0	121	344
Count		97.0	97.0	97	97
Average		4	1.4	182	318
Minimum		.2	.0	62	210
Maximum		11.0	9.9	380	550

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Table B-12. Lake Hills Street Dirt Loadings
(Wet season, with street cleaning)

Sample Date	Sample Ident.	Days from last sign. rain	Days from last cleaning	Loading (lb/curb-mile)	Median size (microns)
10/1/80	S-187	1.4	1.8	228	329
10/1	S-188	1.6	.1	239	341
10/3	S-192	3.4	1.9	229	311
10/3	S-193	3.6	.1	200	279
10/6	S-194	6.4	2.9	244	281
10/6	S-195	6.6	.1	250	259
10/10	S-201	10.4	1.8	216	351
10/10	S-202	10.6	.1	214	272
10/13	S-203	13.4	3.0	124	665
10/13	S-204	13.6	.1	148	342
10/17	S-210	17.4	3.9	182	316
10/17	S-211	17.6	.1	199	255
10/22	S-215	22.4	4.9	198	349
10/22	S-216	22.6	.0	211	310
10/24	S-219	24.4	1.8	212	257
10/27	S-220	27.6	.0	201	300
10/29	S-224	29.4	1.9	250	341
10/29	S-225	29.6	.1	235	297
11/5	S-228	1.5	6.9	167	964
11/5	S-229	1.7	.1	123	465
11/10	S-230	1.7	.0	130	626
11/12	S-231	3.4	1.8	150	629
11/12	S-232	3.6	.1	148	413
11/17	S-233	8.4	2.9	161	720
11/17	S-234	8.7	.1	147	485
11/19	S-238	10.5	1.9	110	>6370
11/19	S-239	10.6	.0	112	473
11/24	S-240	2.7	.1	112	461
11/26	S-241	4.5	1.9	108	755
11/26	S-242	4.6	.1	121	491
12/5	S-243	.7	2.1	159	679
12/15	S-246	10.7	.0	145	464
1/5/81	S-247	4.5	4.9	261	455
1/5	S-248	4.6	.0	210	316
1/7	S-250	6.5	4.9	144	592
1/7	S-251	6.7	.1	179	375
1/9	S-255	8.5	1.9	270	421
1/9	S-256	8.7	.1	197	340
1/12	S-257	12.5	2.9	242	348
1/12	S-258	12.7	.1	214	314
1/14	S-261	14.5	1.9	187	491
1/19	S-265	19.5	6.9	194	444
1/19	S-266	19.6	.0	191	325
1/21	S-270	21.7	.1	162	321
1/28	S-274	4.2	1.9	138	733
1/30	S-277	1.0	1.9	109	608
1/30	S-278	1.2	.1	310	275
2/2	S-279	4.0	2.9	185	479

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Table B-12. Lake Hills Street Dirt Loadings(cont.)
(Wet season, with street cleaning)

Sample Date	Sample Ident.	Days from last sign. rain	Days from last cleaning	Loading (lb/curb-mile)	Median size (microns)
2/2	S-280	4.2	.1	300	256
2/4	S-281	6.0	1.9	190	290
2/4	S-282	6.2	.1	215	229
2/6	S-286	8.0	1.9	277	326
2/9	S-287	11.0	4.9	274	384
2/9	S-288	11.2	.1	186	336
2/18	S-293	1.4	4.7	277	427
2/18	S-294	1.6	.1	195	424
2/20	S-297	.9	1.9	298	339
2/20	S-299	1.0	.1	224	304
2/23	S-300	3.9	2.9	269	264
2/23	S-301	4.1	.1	194	293
2/25	S-302	.8	2.0	166	355
2/27	S-306	2.5	3.9	190	324
2/27	S-307	2.7	.1	436	264
Count		63.0	63.0	63	62
Average		8.7	1.6	200	>405
Minimum		.7	.0	108	229
Maximum		29.6	6.9	436	>6370

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BOTTOM OF IMAGE AREA: OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS

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Table B-13. 148th Ave. SE Street Dirt Loadings
(Dry season, no street cleaning)

Sample Date	Sample Ident.	Days from last sign. rain	Loading (lb/curb-mile)	Median size (microns)
3/26/81	A-343	1.4	290	335
4/2	A-354	2.0	255	406
4/9	A-368	1.0	300	399
4/16	A-380	4.7	407	417
4/23	A-392	1.2	401	696
5/1	A-414	3.1	294	411
5/8	A-436	.7	225	413
5/28	A-474	3.2	268	332
6/5	A-487	11.1	116	866
6/12	A-492	.3	286	498
6/25	A-507	7.1	429	415
7/2	A-517	1.5	162	236
7/10	A-527	3.0	115	382
7/16	A-532	2.8	171	401
7/23	A-540	10.0	162	395
7/28	A-545	14.9	216	510
8/6	A-549	23.9	198	319
8/13	A-556	30.9	196	524
8/20	A-563	37.9	191	422
8/27	A-568	43.9	180	412
9/3	A-577	2.4	270	366
9/10	A-584	9.4	214	279
9/17	A-591	16.4	233	248
Count		23.0	23	23
Average		3.1	273	447
Minimum		.3	115	236
Maximum		43.9	429	866

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Table B-14. 148th Ave. SE Street Dirt Loadings
(Wet season, no street cleaning)

Sample Date	Sample Ident.	Days from last sign. rain	Loading (lb/curb-mile)	Median size (microns)
10/1/81	A-604	2.2	234	329
10/16	A-615	7.6	124	439
11/10	A-638	13.4	174	548
12/17	A-664	1.8	487	446
1/14/81	A-669	2.8	1588	1135
Count		5.0	5	5
Average		5.6	521	579
Minimum		1.8	124	329
Maximum		13.4	1588	1135

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Table B-14a STREET DIRT QUALITY: SURREY DOWNS - MAIN BASIN

Particle Size (Microns)

date	mg/kg COD	<63	63-125	125-250	250-500	500-1000	1000-2000	2000-6350	>6350
3/3 - 5/26/80		120,000	129,000	76,600	41,400	59,000	155,000	113,000	84,800
5/26 - 7/14		156,000	124,000	88,900	43,500	43,500	262,000	90,000	119,000
7/14 - 9/15		177,000	167,000	122,000	97,300	116,000	192,000	174,000	217,000
9/15 - 11/24		185,000	141,000	93,500	98,300	125,000	222,000	263,000	315,000
11/24 - 2/2/81		157,500	112,000	97,100	103,000	202,000	275,000	221,000	623,000
2/2 - 4/13		188,000	131,000	86,600	80,700	174,000	184,000	177,000	195,000
4/13 - 7/2		198,000	166,000	128,000	145,000	167,000	161,000	171,000	89,800
7/3 - 9/18		239,000	217,000	185,000	182,000	196,000	240,000	233,000	261,000
9/23 - 11/20		186,000	140,000	88,000	86,400	107,000	156,000	171,000	545,000
11/24 - 1/16/82		182,000	135,000	79,200	65,400	82,600	55,200	64,700	352,000
mean		179,000	146,000	103,400	94,300	127,200	190,200	167,800	280,200
standard deviation		31,000	30,200	32,300	43,200	56,100	64,400	63,200	184,400
stand. dev./mean		0.17	0.21	0.31	0.46	0.44	0.39	0.38	0.66

date	mg/kg TKN	<63	63-125	125-250	250-500	500-1000	1000-2000	2000-6350	>6350
3/3 - 5/26/80		602	2280	196	182	182	910	189	1870
5/26 - 7/14		2770	2400	1310	1110	546	966	686	286
7/14 - 9/15		3100	2290	2070	1310	1270	1420	1040	154
9/15 - 11/24		2890	1570	2520	1420	1615	1940	1780	1470
11/24 - 2/2/81		2175	1710	1200	1050	1830	2330	1600	248
2/2 - 4/13		2950	2080	1260	1260	1660	1700	1230	1150
4/3 - 7/2		3950	3710	2400	1930	1950	1880	1750	2240
7/3 - 9/18		4620	5350	3800	3010	3140	2685	1390	782
9/23 - 11/20		3055	2180	1180	1040	1270	1490	1560	3910
11/24 - 1/16/82		3130	1880	900	430	770	915	1044	2590
mean		2920	2550	1680	1270	1420	1620	1230	1470
standard deviation		1050	1150	1030	780	830	610	505	1210
stand. dev./mean		0.36	0.45	0.61	0.62	0.59	0.37	0.41	0.82

Table B-14a STREET DIRT QUALITY: SURREY DOWNS - MAIN BASIN (cont.)

Particle Size (Microns)

date	mg/kg Total Phos <63	63-125	125-250	250-500	500-1000	1000-2000	2000-6350	>6350
3/3 - 5/26/80	835	597	319	331	419	553	689	798
5/26 - 7/14	898	571	366	313	347	605	763	636
7/14 - 9/15	240	429	517	396	393	975	1080	971
9/15 - 11/24	889	649	499	430	669	807	755	932
11/24- 2/2/81	476	273	329	420	627	629	641	732
2/2 - 4/13	887	665	525	443	356	749	772	600
4/13 - 7/2	934	625	472	412	546	621	818	730
7/3 - 9/18	1080	887	703	595	569	728	654	612
9/23 - 11/20	1065	723	475	432	504	552	618	697
11/24 - 1/16/82	971	627	425	375	385	651	690	686
mean	830	605	465	415	480	690	750	740
standard deviation	265	165	113	77	117	131	133	127
stand. dev./mean	0.32	0.27	0.24	0.19	0.24	0.19	0.18	0.17

date	mg/kg Lead							
3/3 - 5/26/80	1400	1100	985	600	550	280	190	180
5/26 - 7/14	1600	1400	1200	810	470	340	180	110
7/14 - 9/15	1800	1600	1400	905	1200	540	240	92
9/15 - 11/24	1500	1400	1200	820	440	280	130	200
11/24 - 2/2/81	1100	1100	970	1100	520	400	585	900
2/2 - 4/13	1100	680	720	470	355	230	150	120
4/13 - 7/2	1200	1100	920	670	430	330	210	640
7/3 - 9/18	1500	1400	1200	990	1200	790	330	58
9/23 - 11/20	1500	1200	1000	1100	1000	790	130	182
11/24 - 1/16/82	1500	1100	910	930	620	220	210	350
mean	1420	1210	1050	840	680	420	235	280
standard deviation	225	255	200	210	330	216	136	276
stand. dev./mean	0.16	0.21	0.19	0.25	0.48	0.51	0.58	0.98

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Table B-14a. STREET DIRT QUALITY: SURREY DOWNS - MAIN BASIN (cont.)

	Particle Size (Microns)							
date mg/kg Zinc	< 63	63-125	125-250	250-500	500-1000	1000-2000	2000-6350	>6350
3/3 - 5/26/80	287	224	189	131	152	102	327	85
5/26 - 7/14	270	247	228	178	168	117	87	80
7/14 - 9/14	379	288	230	164	170	98	67	74
9/15 - 11/24	412	354	248	194	133	137	82	102
11/24 - 2/2/81	252	239	199	121	151	147	120	176
2/2 - 4/13	259	188	125	126	120	116	72	66
4/13 - 7/2	292	239	220	182	135	101	75	64
7/3 - 9/18	371	295	246	210	194	181	88	75
9/23 - 11/20	340	264	196	182	213	118	85	116
11/24 - 1/16/82	308	232	185	135	154	99	97	150
mean	317	257	207	168	159	122	110	99
standard deviation	55	46	37	29	28	27	78	38
stand. dev./mean	0.18	0.18	0.18	0.17	0.18	0.22	0.71	0.38

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Table B-15 STREET DIRT QUALITY SURREY DOWNS - 108th AVENUE

Particle Size (Microns)

date	mg/kg COD	<63	63-125	125-250	250-500	500-1000	1000-2000	2000-6350	>6350
3/3 - 5/26/80		122,000	92,500	48,700	47,200	28,500	23,600	53,800	73,900
5/26 - 7/11		139,000	21,200	42,000	26,000	16,000	20,400	204,000	213,000
7/14 - 9/15		128,000	262,000	37,450	28,400	25,200	20,100	19,400	18,400
9/15 - 11/24		140,000	69,600	36,600	27,400	29,300	24,100	23,600	17,500
11/24 - 2/2/81		179,000	132,000	105,000	62,800	84,700	85,800	85,100	151,000
2/2 - 4/13		141,000	86,700	57,300	36,800	40,500	36,900	47,600	33,400
4/13 - 7/2		148,000	88,200	51,300	33,900	28,200	11,600	19,100	14,000
7/3 - 9/18		142,000	81,400	35,200	26,400	20,200	24,900	14,600	13,800
9/23 - 11/20		149,000	90,600	61,400	27,600	37,800	63,900	70,700	65,400
11/24 - 1/16/82		189,000	118,000	59,700	45,100	62,000	58,200	13,700	95,700
mean		147,700	104,200	53,500	36,200	37,200	36,900	55,200	69,600
standard deviation		20,900	62,700	20,600	12,100	21,000	24,200	58,000	67,300
stand. dev./mean		0.14	0.60	0.38	0.34	0.57	0.65	1.05	0.97

date	mg/kg TKN	<63	63-125	125-250	250-500	500-1000	1000-2000	2000-6350	>6350
3/3 - 5/26/80		1680	665	315	266	245	168	133	98
5/26 - 7/14		1440	2100	889	470	833	105	147	140
7/14 - 9/15		300	882	341	236	221	207	67	281
9/15 - 11/24		1640	859	451	293	276	150	120	96
11/24 - 2/2/81		2580	1760	2550	713	743	868	720	1340
2/2 - 4/13		1735	1060	545	367	433	442	348	245
4/13 - 7/2		1980	1230	595	296	291	244	286	223
7/3 - 9/18		1930	1150	2480	453	208	209	164	146
9/23 - 11/20		2020	1090	580	327	654	442	439	532
11/24 - 1/16/82		2710	1440	902	653	668	565	515	409
mean		1800	1220	965	407	457	340	294	351
standard deviation		663	436	840	164	243	239	211	375
stand. dev./mean		0.37	0.36	0.87	0.40	0.53	0.70	0.72	1.07

Table B-15 STREET DIRT QUALITY SURREY DOWNS - 108th AVENUE (cont.)

Particle Size (Microns)

date	mg/kg TP	<63	63-125	125-250	250-500	500-1000	1000-2000	2000-6350	>6350
3/3 - 5/26/80		661	403	287	275	393	576	630	628
5/26 - 7/14		539	1080	316	316	367	601	581	470
7/14 - 9/15		686	473	236	182	193	365	332	185
9/15 - 11/24		672	472	314	325	384	678	766	791
11/24 - 2/2/81		417	360	369	393	446	674	664	610
2/2 - 4/13		706	461	389	306	418	672	726	767
4/13 - 7/2		666	389	320	204	402	680	712	617
7/3 - 9/18		748	463	334	268	295	602	625	624
9/23 - 11/20		840	455	413	386	440	573	475	731
11/24 - 1/16/82		972	502	354	382	461	767	883	739
mean		691	506	333	304	380	619	639	616
standard deviation		151	207	51	73	81	108	154	179
stand. dev./mean		0.22	0.41	0.15	0.24	0.21	0.17	0.24	0.29

date	mg/kg Lead								
3/3 - 5/26/80		2000	1900	1600	980	1000	350	130	55
5/26 - 7/14		2250	2100	2100	1100	500	320	190	52
7/14 - 9/15		1600	1600	1800	770	700	400	92	48
9/15 - 11/24		2200	1800	1500	1200	610	200	88	42
11/24 - 2/2/81		1100	850	870	900	590	300	230	230
2/2 - 4/13		1100	945	840	570	350	140	140	280
4/13 - 7/2		1500	1100	1300	920	320	165	210	30
7/3 - 9/18		1700	1600	1300	1100	930	190	95	30
9/23 - 11/20		1300	1100	1000	800	259	139	87	65
11/24 - 1/16/82		1500	1100	1200	720	400	170	76	77
mean		1630	1410	1350	910	566	237	134	91
standard deviation		416	442	407	196	253	96	57	88
stand. dev./mean		0.26	0.31	0.30	0.22	0.45	0.40	0.42	0.97

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Table B-15 STREET DIRT QUALITY SURREY DOWNS - 108th AVENUE (cont.)

date	mg/kg Zinc	Particle Size (Microns) <63	63-125	125-250	250-500	500-1000	1000-2000	2000-6350	>6350
3/3 - 5/26/80		262	233	191	137	123	112	69	70
5/26 - 7/14		296	260	188	114	229	103	75	50
7/14 - 9/15		233	192	131	109	89	110	62	53
9/15 - 11/24		332	210	197	156	151	105	77	108
11/24 - 2/2/81		257	172	176	128	122	118	106	98
2/2 - 4/13		250	180	131	99	109	254	283	861
4/13 - 7/2		249	179	120	91	92	171	82	61
7/3 - 9/18		264	192	151	124	170	90	89	56
9/23 - 11/20		310	228	164	122	115	99	76	62
11/24 - 1/16/82		283	226	142	111	101	111	79	64
mean		274	207	159	119	130	127	99	148
standard deviation		31	29	28	19	43	50	65	251
stand. dev./mean		0.11	0.14	0.18	0.16	0.33	0.39	0.66	1.7

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Table B-16 STREET DIRT QUALITY: SURREY DOWNS - WESTWOOD HOMES ROAD

	Particle Size (Microns)							
date mg/kg COD	<63	63-125	125-250	250-500	500-1000	1000-2000	2000-6350	>6350
5/26 - 7/14/80	132,000	159,000	124,000	146,000	155,000	348,000	364,000	437,000
7/14 - 9/15	166,000	164,000	205,000	193,000	161,000	259,000	393,000	125,000
9/15 - 11/24	173,000	162,000	87,000	80,000	160,000	183,000	364,000	361,000
11/24 - 2/2/81	168,000	144,000	165,000	175,000	152,000	367,000	367,000	733,000
2/2 - 4/13	208,000	212,000	143,000	166,000	215,000	339,000	214,000	457,000
4/13 - 7/2	242,000	226,000	169,000	178,000	173,000	170,000	124,000	117,000
7/3 - 9/18	249,000	274,000	232,000	185,000	198,000	252,000	245,000	161,000
9/23 - 11/20	175,000	167,000	114,000	91,900	169,000	282,000	320,000	640,000
mean	189,000	188,500	154,900	151,900	172,900	275,100	298,900	378,900
standard deviation	40,400	44,500	48,000	43,100	22,300	73,900	95,000	234,200
stand. dev./mean	0.21	0.24	0.31	0.28	0.13	0.27	0.32	0.62

date mg/kg TKN								
5/26 - 7/14	2680	2290	1200	574	2480	2900	653	437
7/14 - 9/15	2990	3290	1900	1140	1470	1770	1990	408
9/15 - 11/24	2780	2290	1370	1250	1760	1980	2340	2050
11/24 - 2/2/81	2130	1710	1400	1550	1680	2280	6150	2190
2/2 - 4/13	3270	2940	2130	2040	1490	2230	1730	2400
4/13 - 7/2	4550	4740	3450	2350	2240	3530	1590	773
7/3 - 9/18	4930	6000	4830	3190	2580	2730	1820	1170
9/23 - 11/20	3160	3295	1810	1290	1830	2340	3110	4850
mean	3310	3320	2260	1670	1940	2470	2420	1780
standard deviation	953	1420	1260	822	435	563	1660	1470
stand. dev./mean	0.29	0.43	0.56	0.49	0.22	0.23	0.68	0.83

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Table B-16. STREET DIRT QUALITY: SURREY DOWNS - WESTWOOD HOMES ROAD (cont.)

Particle Size (Microns)

date	mg/kg TP	< 63	63-125	125-250	250-500	500-1000	1000-2000	2000-6350	> 6350
5/26 - 7/14		855	853	393	1250	424	573	740	829
7/14 - 9/15		489	359	511	346	470	627	657	780
9/15 - 11/24		810	652	---	341	718	642	609	585
11/24 - 2/2/81		619	436	389	572	772	519	546	448
2/2 - 4/13		771	570	410	352	424	557	569	454
4/13 - 7/2		875	758	584	417	403	538	668	658
7/3 - 9/18		1010	994	509	529	497	610	658	698
9/23 - 11/20		1060	846	520	391	521	584	654	499
mean		810	684	474	525	529	581	638	619
standard deviation		189	220	76	305	140	43	61	146
stand. dev./mean		0.23	0.32	0.16	0.58	0.26	0.07	0.10	0.24

date	mg/kg Lead	< 63	63-125	125-250	250-500	500-1000	1000-2000	2000-6350	> 6350
5/26 - 7/14		375	321	250	140	580	1900	55	32
7/15 - 9/15		400	320	260	215	89	59	34	23
9/15 - 11/24		390	300	205	140	75	60	35	52
11/24 - 2/2/81		440	350	230	190	200	170	160	360
2/2 - 4/13		415	350	210	160	75	89	50	80
4/13 - 7/2		600	380	370	180	94	52	27	39
7/3 - 9/18		560	400	300	210	83	145	37	24
9/23 - 11/20		340	250	160	190	115	71	30	62
mean		440	334	248	178	164	318	54	84
standard deviation		92	47	64	29	173	641	44	113
stand. dev./mean		0.21	0.14	0.26	0.16	1.1	2.0	0.82	1.35

Table B-16.
Street Dirt Quality: Surrey Downs - Westwood Homes Rd. (con't)

Particle Size (Microns)

Date	mg/kg Zinc <63	63 -125	125 -250	250 -500	500 -1000	1000 -2000	2000 -6350	>6350
5/26-7/14	177	158	96	69	94	125	65	55
7/14-9/15	152	112	75	88	58	84	45	44
9/15-11/24	169	127	92	71	66	76	63	81
11/24-2/2/81	162	121	102	87	88	100	108	161
2/2-4/13	160	130	99	87	66	145	134	166
4/13-7/2	209	155	126	79	74	67	53	38
7/3-9/18	228	177	115	89	72	88	63	55
9/23-11/20	177	139	82	68	81	108	64	76
mean	179	140	98	80	75	99	74	85
standard dev.	26	22	17	9.2	12	26	30	51
stand. dev./mean	0.15	0.16	0.17	0.11	0.16	0.26	0.41	0.60

Table B-17.
Street Dirt Quality: Lake Hills

		Particle Size (Microns)						
Date mg/kg COD	< 63	63 -125	125 -250	250 -500	500 -1000	1000 -2000	2000 -6350	> 6350
3/3-5/26/80	310,000	322,000	98,800	62,200	199,000	154,000	171,000	118,000
5/26-7/14	201,000	152,000	129,000	111,000	175,000	171,000	234,000	217,500
7/14-9/15	231,000	147,000	130,000	150,000	316,000	244,000	330,000	304,000
9/15-11/24	249,000	174,000	122,000	98,700	253,000	176,000	196,000	276,000
11/24-2/2/81	184,000	131,000	83,800	98,800	156,500	154,000	164,000	474,000
2/2 - 4/13	190,000	99,500	79,400	57,500	101,000	151,000	182,000	236,000
4/13-7/1	206,500	159,000	88,700	97,000	120,000	251,000	230,000	260,000
7/3-9/18	274,000	246,000	137,000	149,000	296,000	344,000	426,000	895,000
9/23-11/20	240,000	164,000	105,000	82,800	191,000	366,000	269,000	663,000
11/24-1/16-82	242,000	176,000	152,000	106,500	301,000	385,000	458,000	778,000
N=10								
mean	232,800	177,100	112,600	101,400	210,800	239,600	266,000	422,000
standard dev.	39,400	63,200	24,900	30,900	77,000	93,900	105,500	267,000
stand. dev./mean	0.17	0.36	0.22	0.30	0.37	0.39	0.40	0.63

Date mg/kg TKN								
3/3-5/26/80	4170	3760	2600	1660	2420	2380	504	805
5/26-7/14	3420	3560	1870	1750	2180	833	2020	1510
7/14-9/15	3230	3100	2160	2270	3160	2610	2470	2480
9/15-11/24	3750	3120	1950	1550	1960	1750	1270	2100
11/24-2/2/'81	2750	1770	974	962	1325	1420	1310	1700
2/2-4/13	2600	1590	1040	806	1060	1790	2240	1660
4/13-7/1	3540	3270	2380	1620	2010	2890	2700	2470
7/3-9/18	4440	5040	3070	2820	4225	1440	1510	4080
9/23-11/20	3965	2730	1490	1375	2330	2410	2200	6630
11/24-1/16/82	3165	3560	1520	1240	2680	3590	3960	8330
mean	3500	3150	1910	1610	2340	2110	2010	3180
standard dev.	590	990	670	590	900	820	950	2460
stand. dev./mean	0.17	0.31	0.35	0.37	0.38	0.39	0.47	0.77

Table B-17.
Street Dirt Quality: Lake Hills (con't.)

date	mg/kg TP <63	63 125	125 250	250 500	500 1000	1000 2000	2000 6350	>6350
	Particle Size (Microns)							
3/3-5/26/80	1060	1370	663	522	650	744	621	508
5/26-7/14	950	718	443	340	557	661	680	494
7/14-9/15	614	444	522	251	135	1230	1220	1010
9/15-11/24	921	730	522	425	537	620	643	866
11/24-2/2/81	738	500	393	467	600	646	636	596
2/2-4/13	876	634	480	499	537	702	793	656
4/13-7/1	832	656	450	221	550	752	709	620
7/3-9/18	1103	904	795	546	913	866	748	1240
9/23-11/20	1390	842	649	652	623	607	613	657
11/24-1/16/82	938	615	533	439	598	798	732	850
mean	942	741	545	436	570	763	740	750
stand. deviation	213	261	123	134	189	183	179	239
stand. dev./mean	0.23	0.35	0.22	0.31	0.33	0.24	0.24	0.32

date	mg/kg Pb							
3/3-5/26/80	2600	2300	1800	1600	820	360	330	130
5/26-7/14	2300	2300	2000	1800	750	700	260	140
7/14-9/15	1600	1900	1800	1400	1100	800	210	130
9/15-11/24	2100	1900	1800	1500	1000	820	200	160
11/24-2/2/81	1700	1500	1200	670	540	520	280	508
2/2-4/13	1500	1300	1100	970	770	470	250	140
4/13-7/1	1350	1700	1800	1100	840	690	170	130
7/3-9/18	2300	2300	2200	1700	1600	850	1100	100
9/23-11/20	2100	2000	1700	1400	710	240	150	240
11/24-1/16/82	1400	1400	1100	1000	530	870	515	420
mean	1895	1860	1650	1310	866	632	347	210
stand. deviation	439	378	384	364	313	222	284	140
stand. dev./mean	0.23	0.20	0.23	0.28	0.36	0.35	0.82	0.67

Table B-17.
Street Dirt Quality: Lake Hills (cont.)

	Particle Size (Microns)							
Date mg/kg Zinc	<63	63 -125	125 -250	250 -500	500 -1000	1000 -2000	2000 -6350	>6350
3/3-5/26	502	347	282	270	179	147	90	79
5/26-7/14	314	320	255	196	145	127	97	75
7/14-9/15	339	370	335	225	254	141	145	121
9/15-11/24	438	382	277	236	183	159	103	109
11/24-2/2/81	310	249	272	182	155	175	143	281
2/2-4/13	342	234	192	144	143	130	89	68
4/13-7/1	316	322	246	219	164	146	91	77
7/13-9/18	420	383	343	281	197	179	283	98
9/23-11/20	416	400	320	283	186	128	135	189
11/24-1/16/82	333	267	216	165	168	440	151	277
mean	373	327	274	220	177	177	133	137
stand. deviation	66	60	49	49	32	94	59	82
stand. dev./mean	0.18	0.18	0.18	0.22	0.18	0.53	0.44	0.60

Table B-18.
Street Dirt Quality - 148th Ave.

	Particle Size (Microns)							
mg/kg COD	<63	63-125	125-250	250-500	500-1000	1000-2000	2000-6350	>6350
4/13-7/1/81	153,000	83,600	52,100	45,500	66,900	77,300	89,100	167,000
9/23-11/20	167,000	102,000	40,300	36,600	138,000	209,000	267,000	228,000
N=2 mean	160,000	93,800	46,200	41,100	102,000	143,000	178,000	198,000
mg/kg TKN								
4/13-7/1/81	1750	993	601	419	986	727	1030	419
9/23-11/20	1530	941	432	520	1030	1270	1060	572
mean	1640	967	517	470	1010	1000	1050	500
mg/kg TP								
4/13-7/1/81	603	319	427	245	357	624	755	583
9/23-11/20	878	614	387	384	456	499	491	508
mean	740	470	410	315	410	560	620	450
mg/kg Lead								
4/13-7/1/81	2400	2400	2200	2000	1300	320	130	89
9/23-11/20	3500	3000	2300	2500	2000	545	170	535
mean	2900	2700	2250	2250	1650	430	150	310
mg/kg Zinc								
4/13-7/1/81	437	317	208	170	141	102	73.5	54.8
9/23-11/20	531	379	251	273	186	205	94.1	93.3
mean	480	350	230	220	160	150	84	74

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FIGURE B-1

SURREY DOWNS-WESTWOOD HOMES RD DIRT ACCUM.

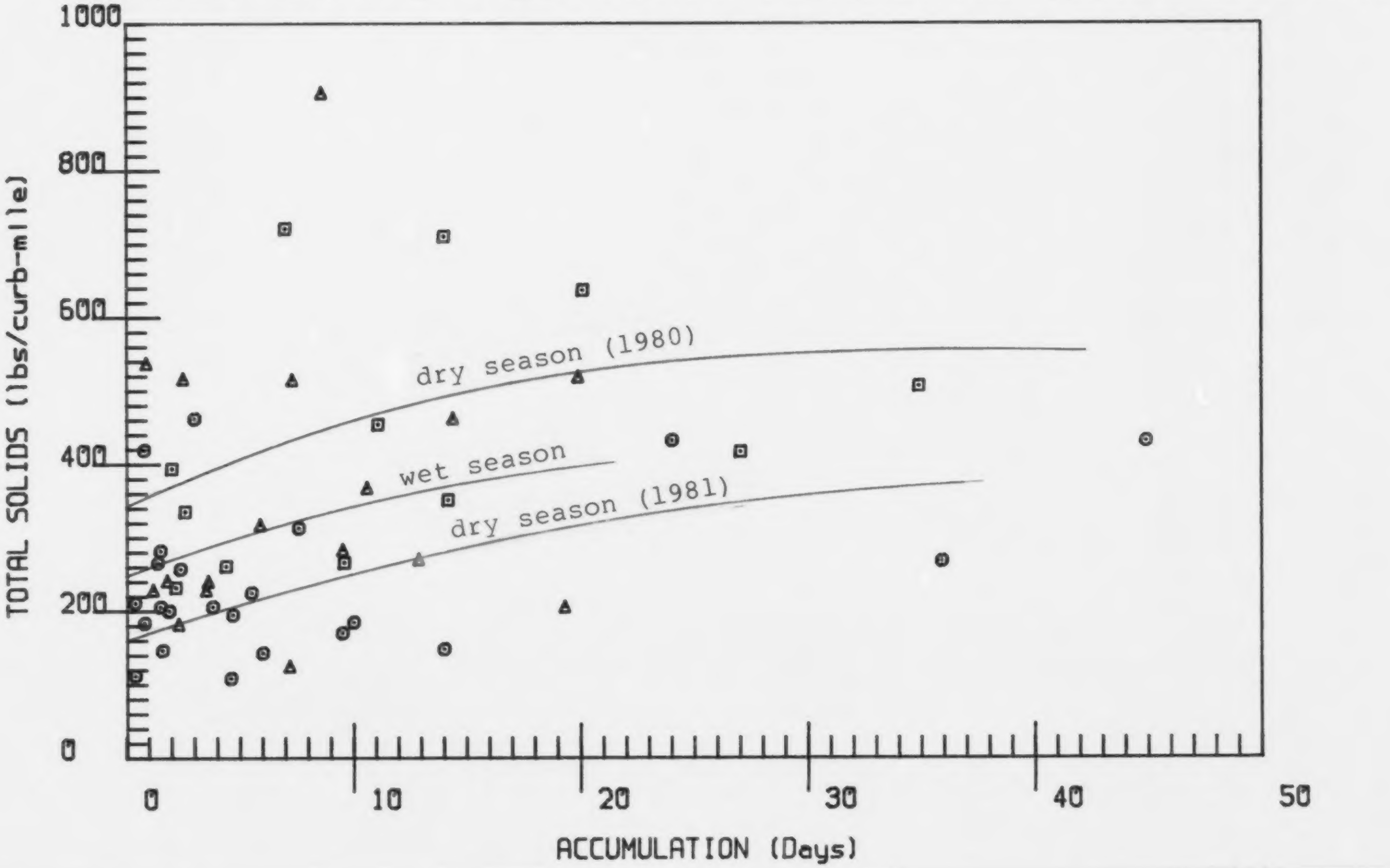

FIGURE B-2

SURREY DOWNS-108th ST. STREET DIRT ACCUM.

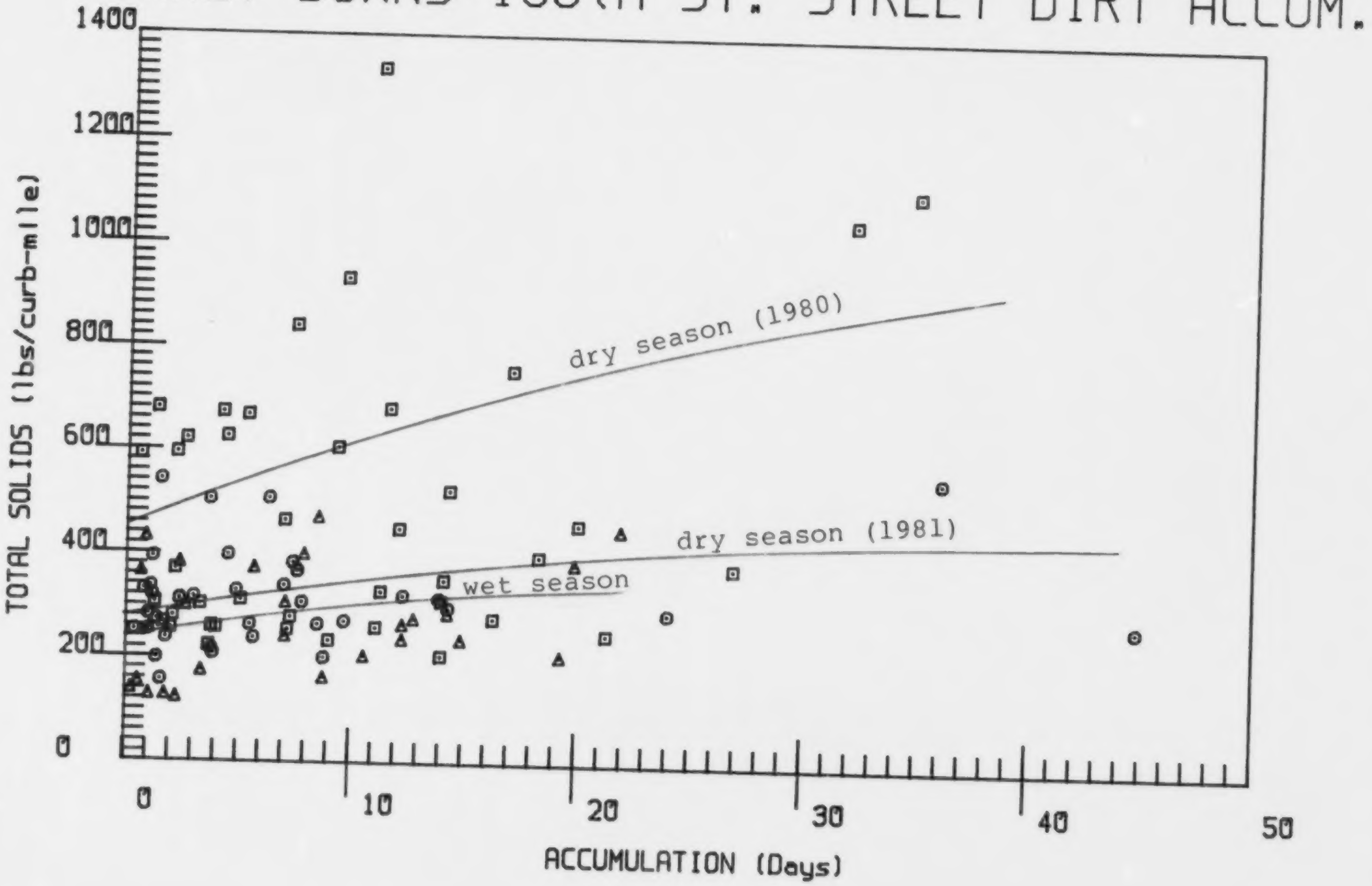

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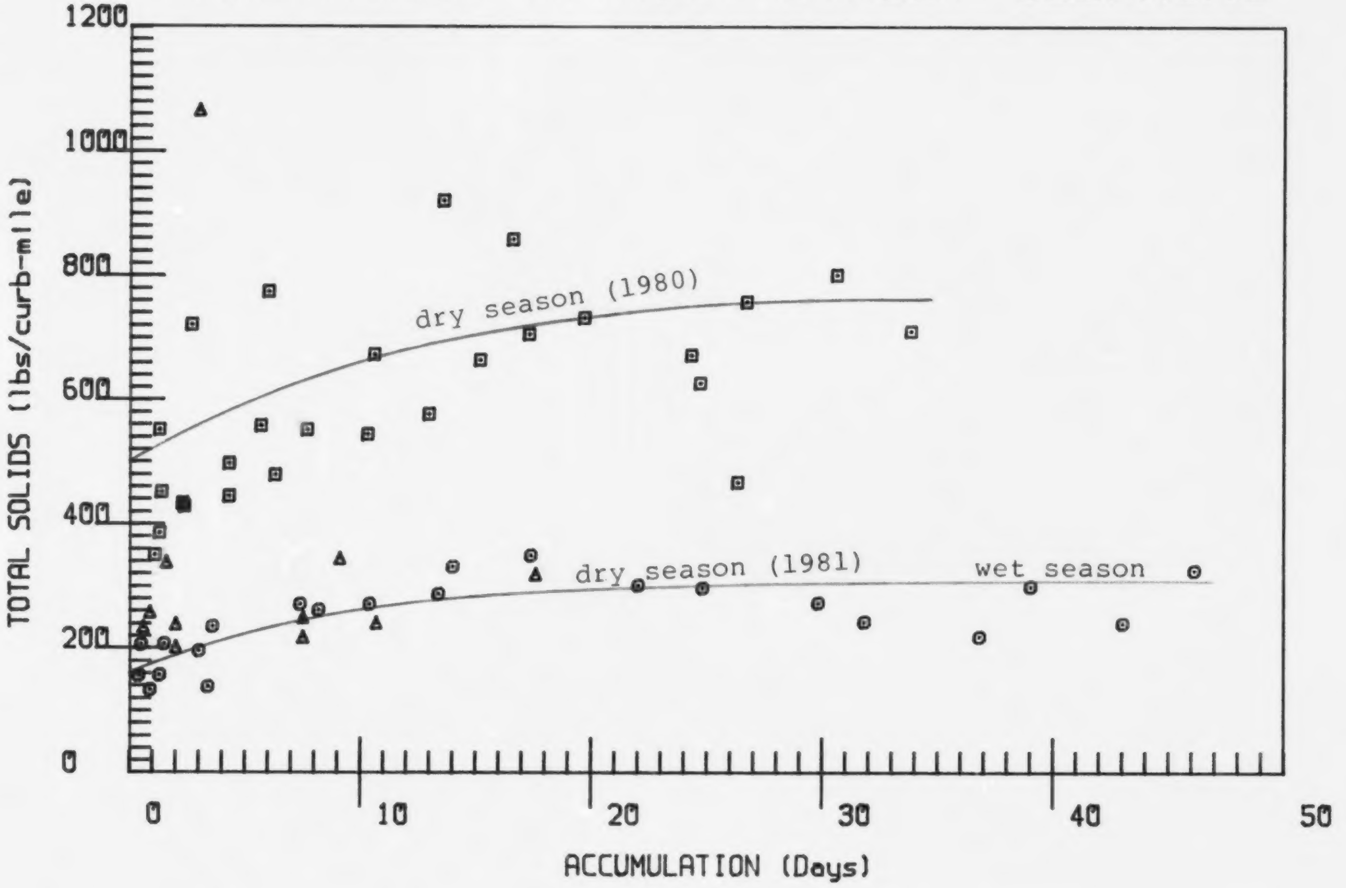
FIGURE B-3

LAKE HILLS-WITHOUT STREET CLEANING



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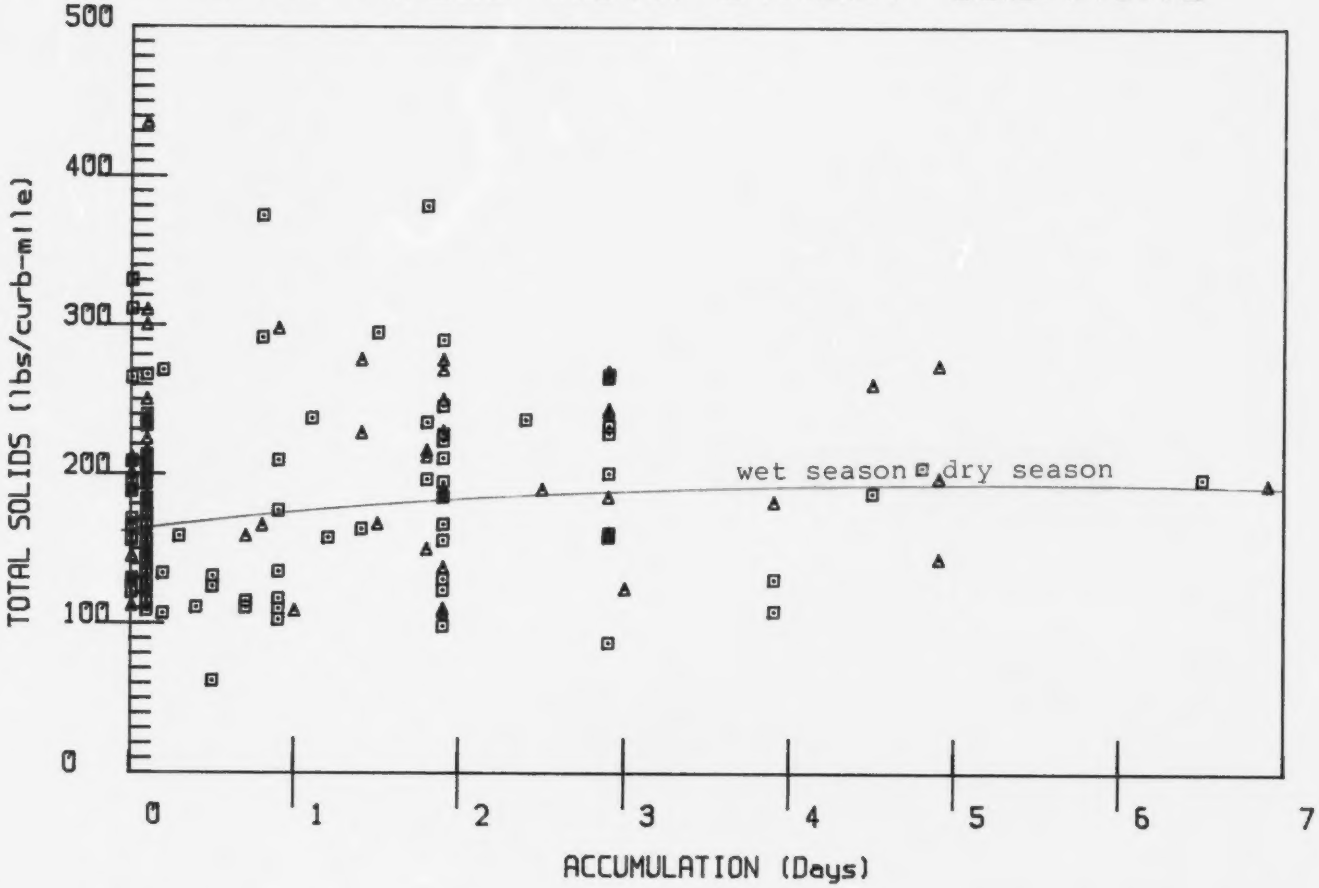
DROPPED HEAD: BEGIN SECTIONS HERE
CENTER OF PAGE
TOP OF IMAGE AREA

FIGURE B-4

LAKE HILLS-WITH STREET CLEANING



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3/8"
BOTTOM OF IMAGE AREA: OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS

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FIGURE B-5

148th Ave. S.E. STREET DIRT ACCUMULATION

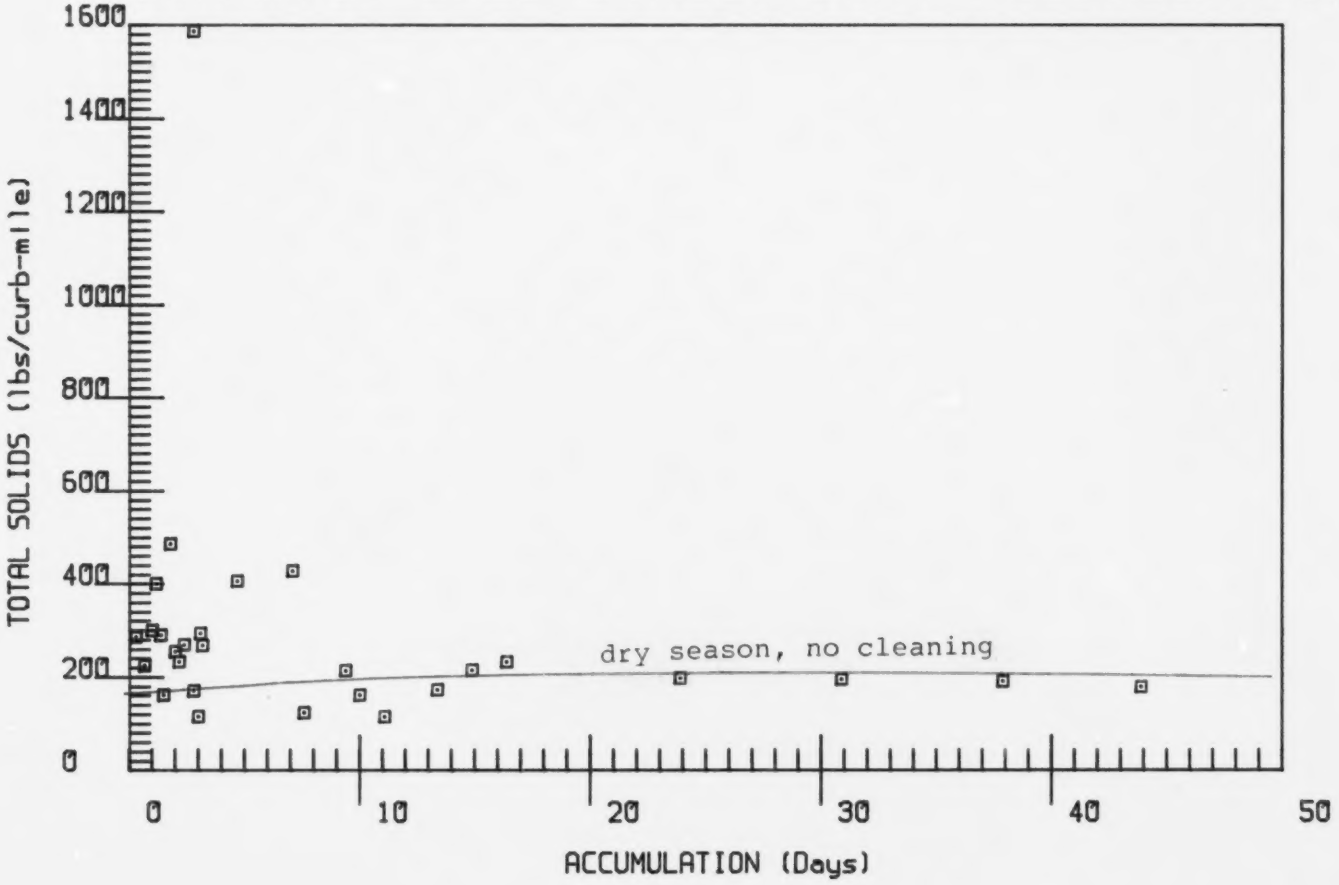

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FIGURE B-6

WET SEASON PARTICLE SIZE DISTRIBUTION

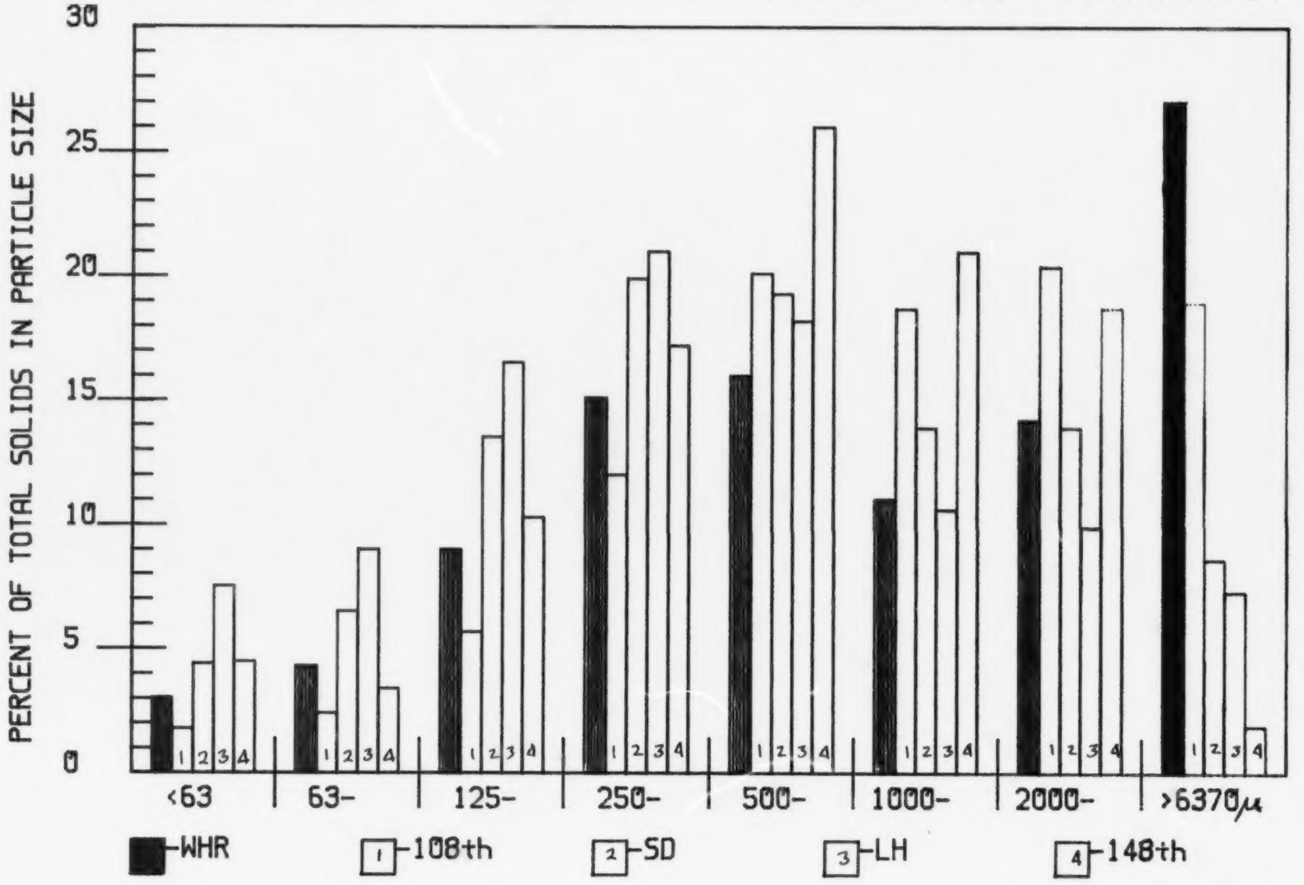

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FIGURE B-7

TKN CONC. BY PARTICLE SIZE (mg/kg)

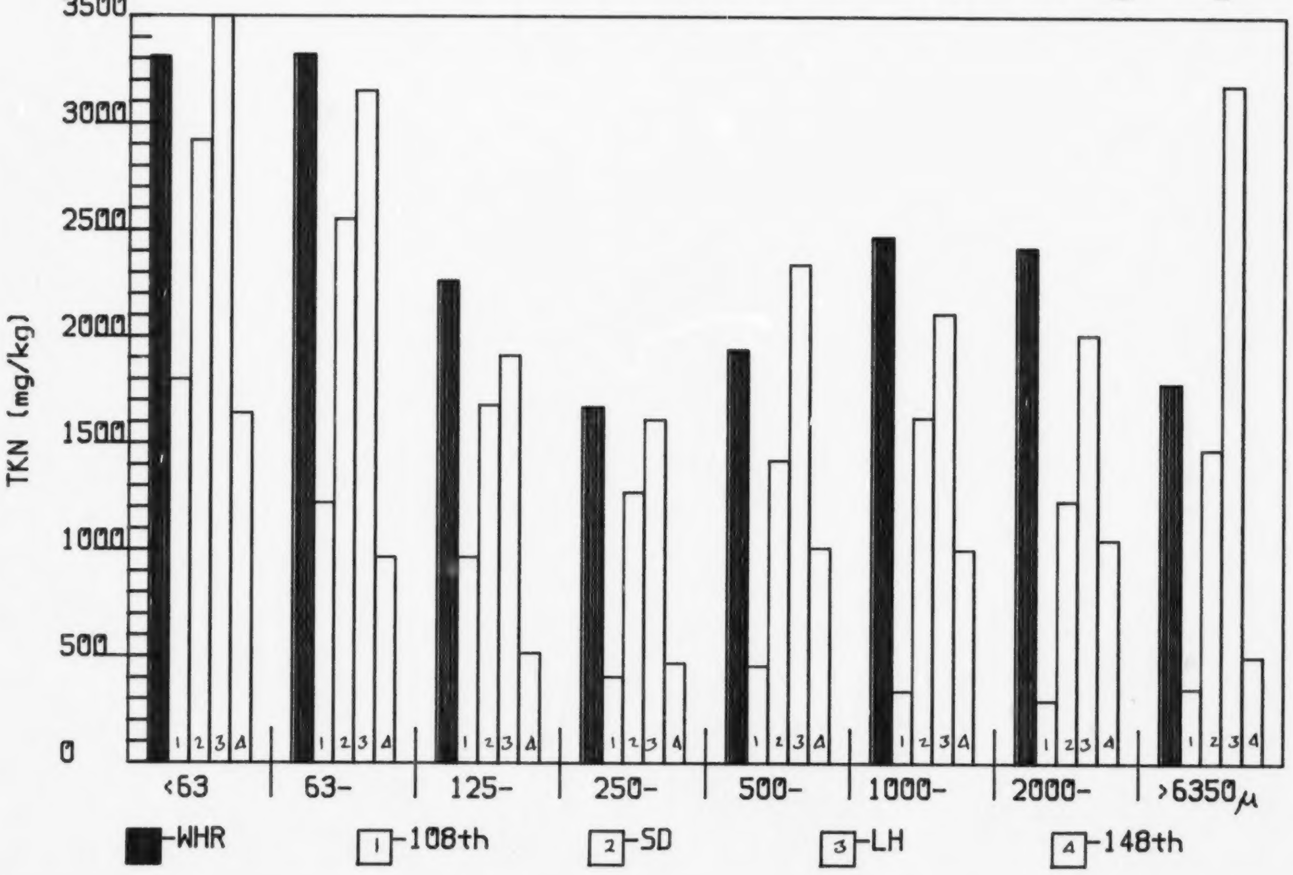

FIGURE B-8

TOTAL PHOS. CONC. BY PARTICLE SIZE (mg/kg)

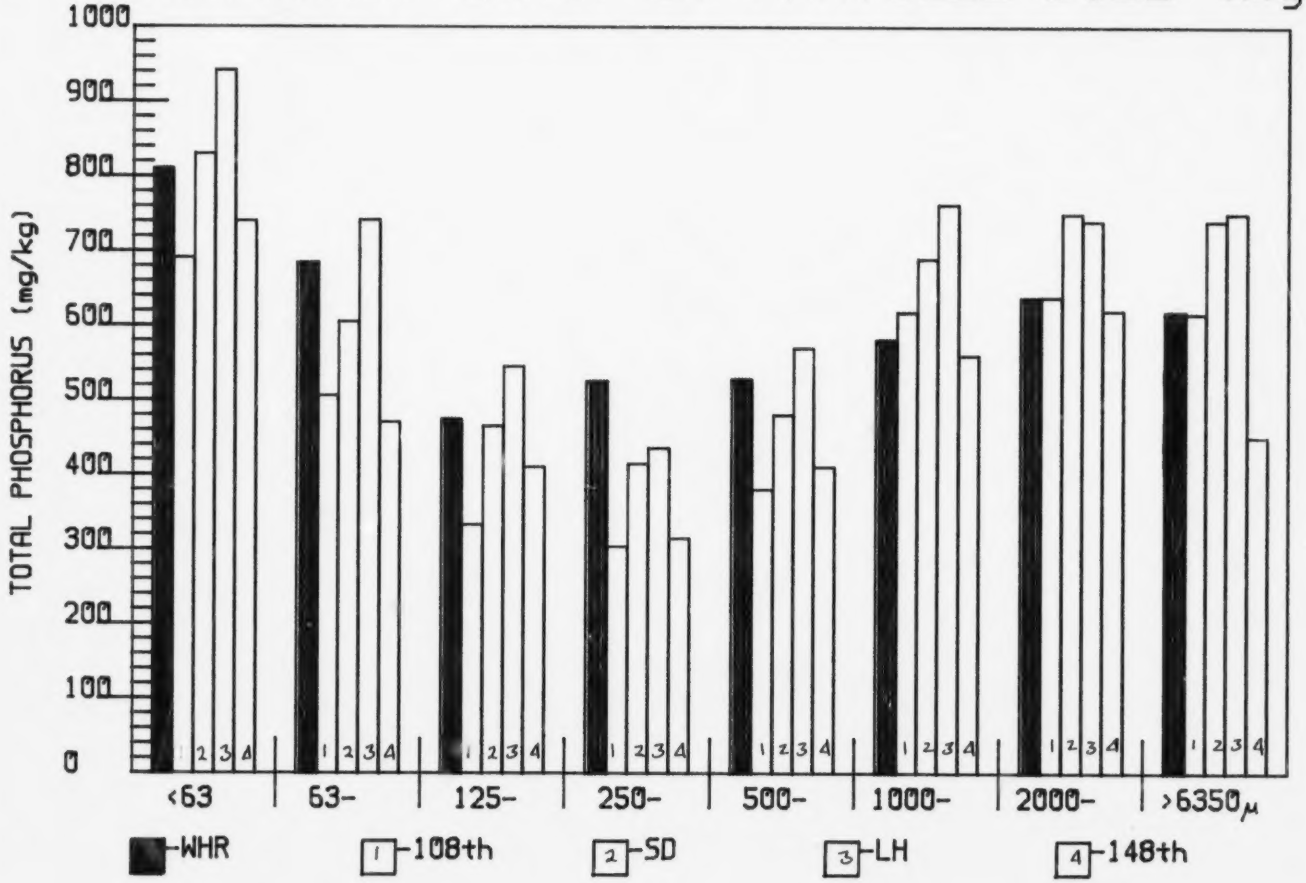

FIGURE B-9

ZINC CONC. BY PARTICLE SIZE (µg/kg)

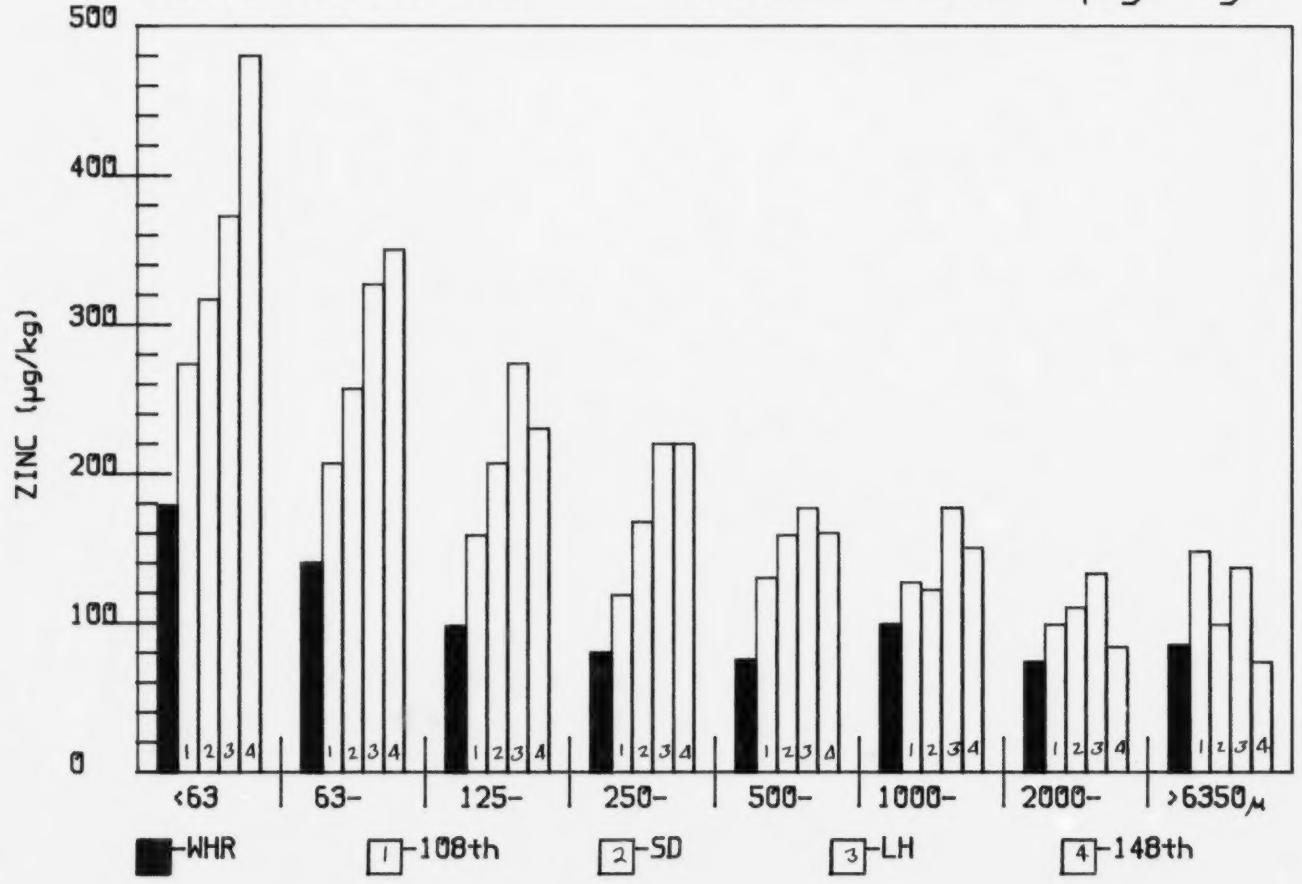

FIGURE B-10

SURREY DOWNS WASHOFF BY RUNOFF VOLUME

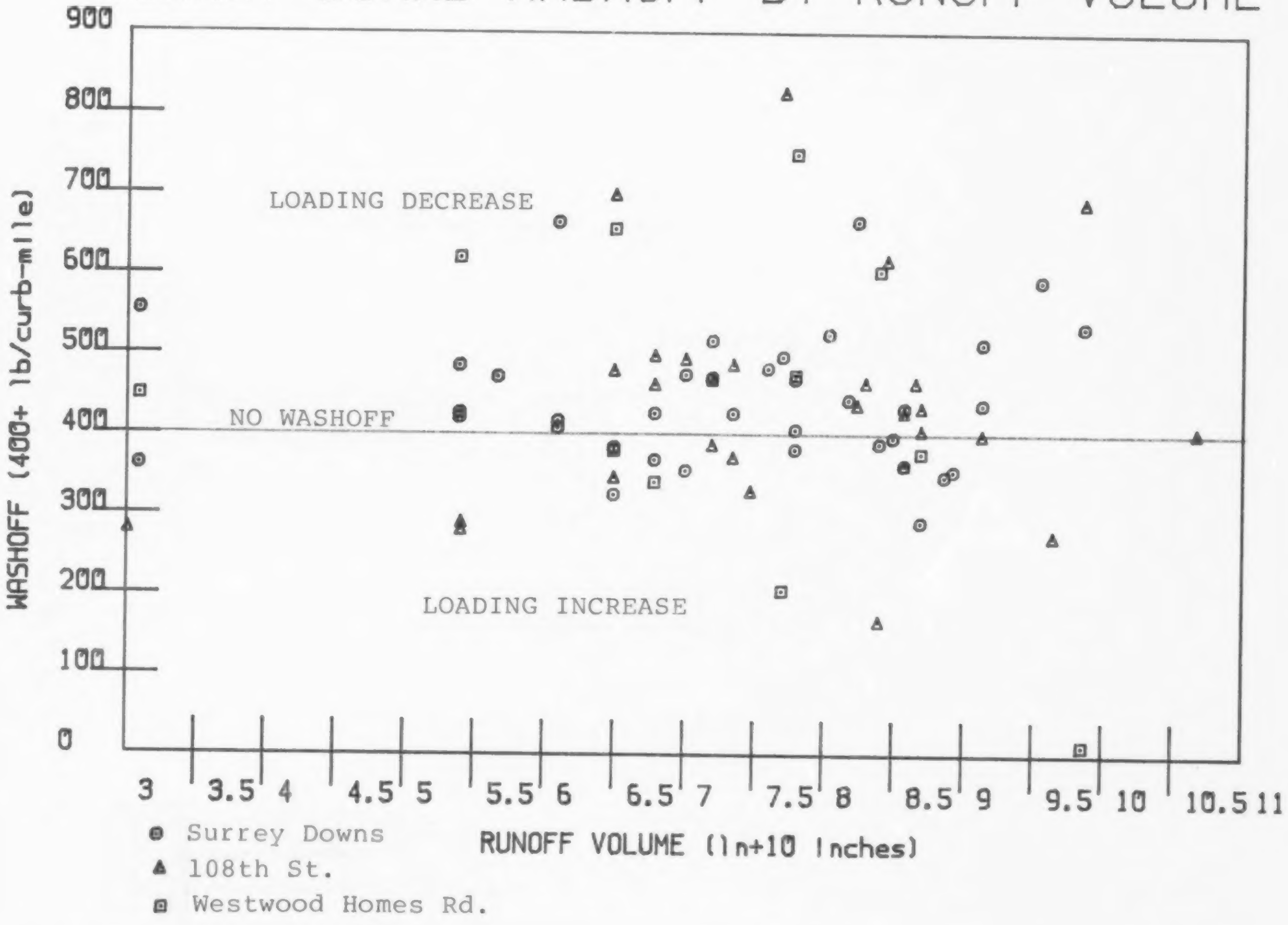

FIGURE B-11

LAKE HILLS & 148th AVE WASHOFF BY RUNOFF

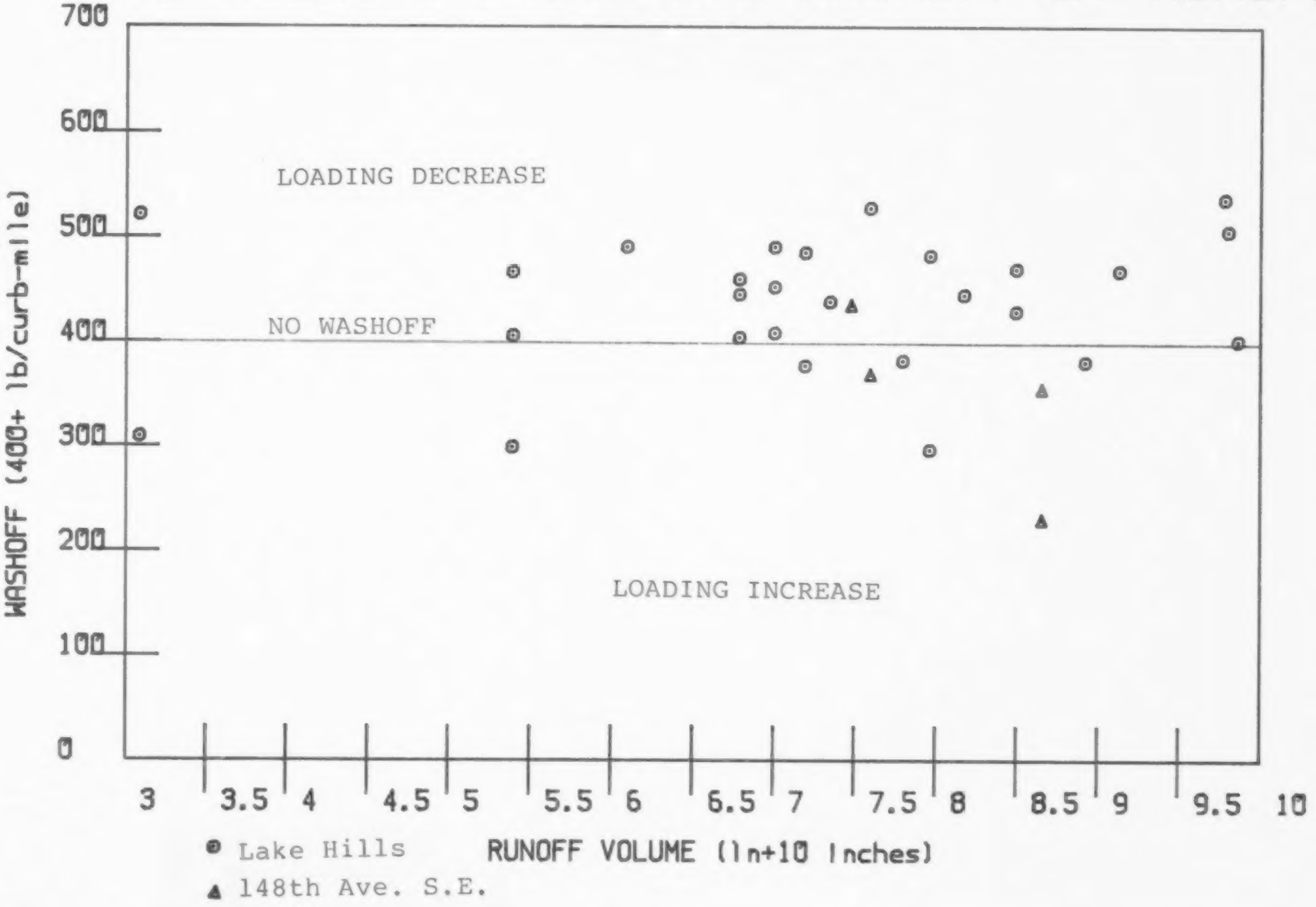

FIGURE B-12

SURREY DOWNS RUNOFF VS RESIDUAL LOAD

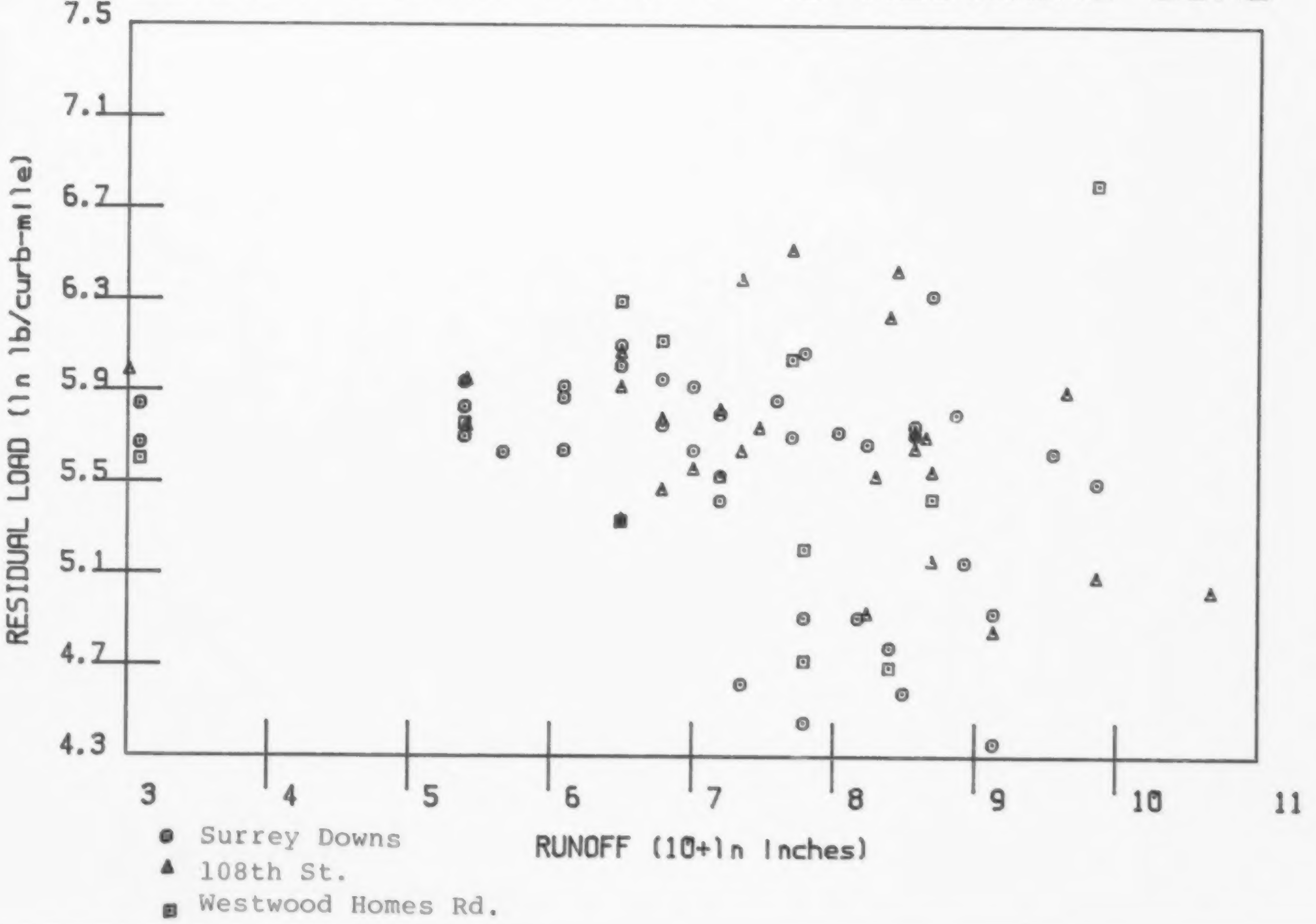

FIGURE B-13

LAKE HILLS & 148th RUNOFF VS RESIDUAL LOAD

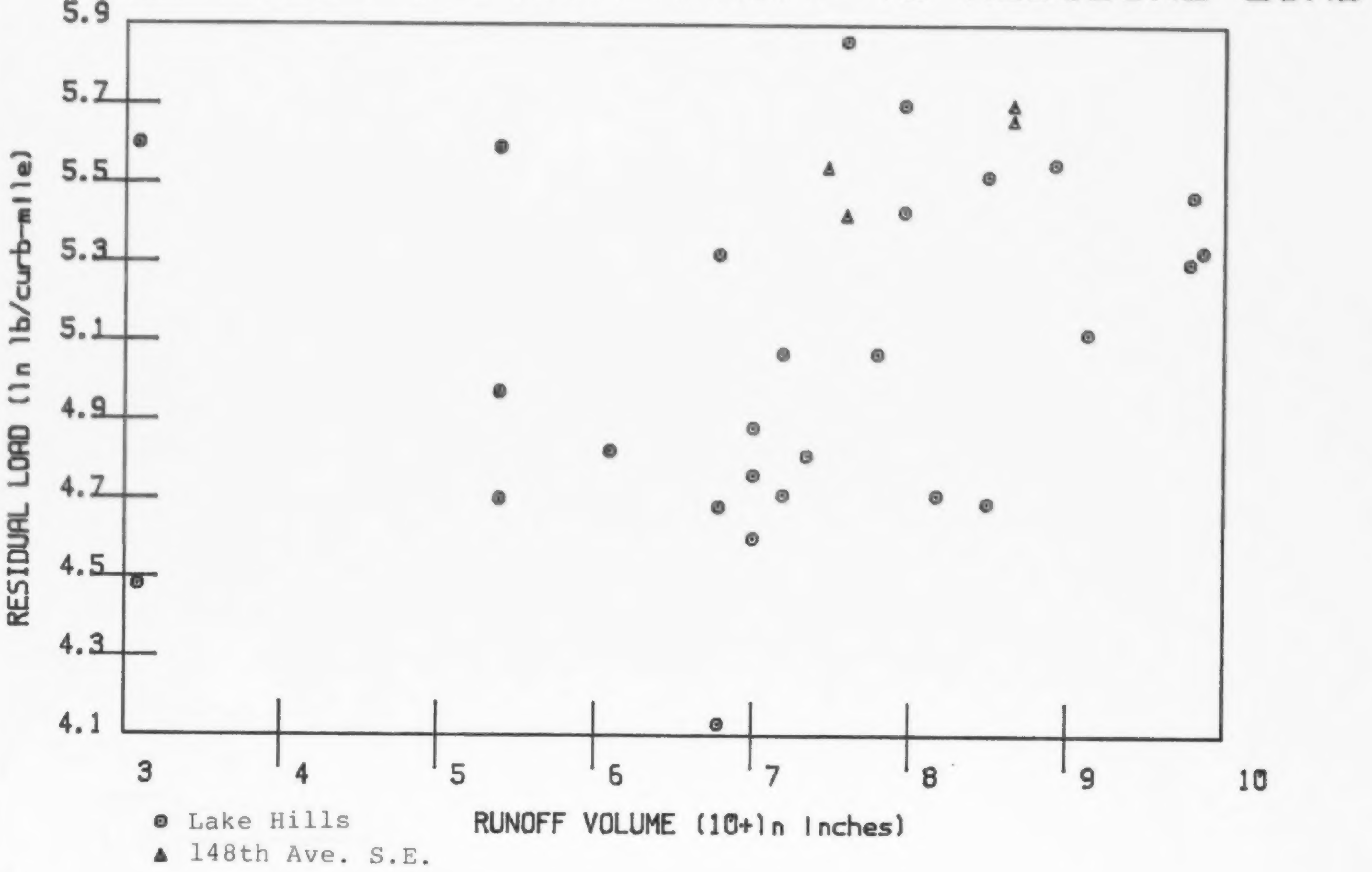

FIGURE B-14

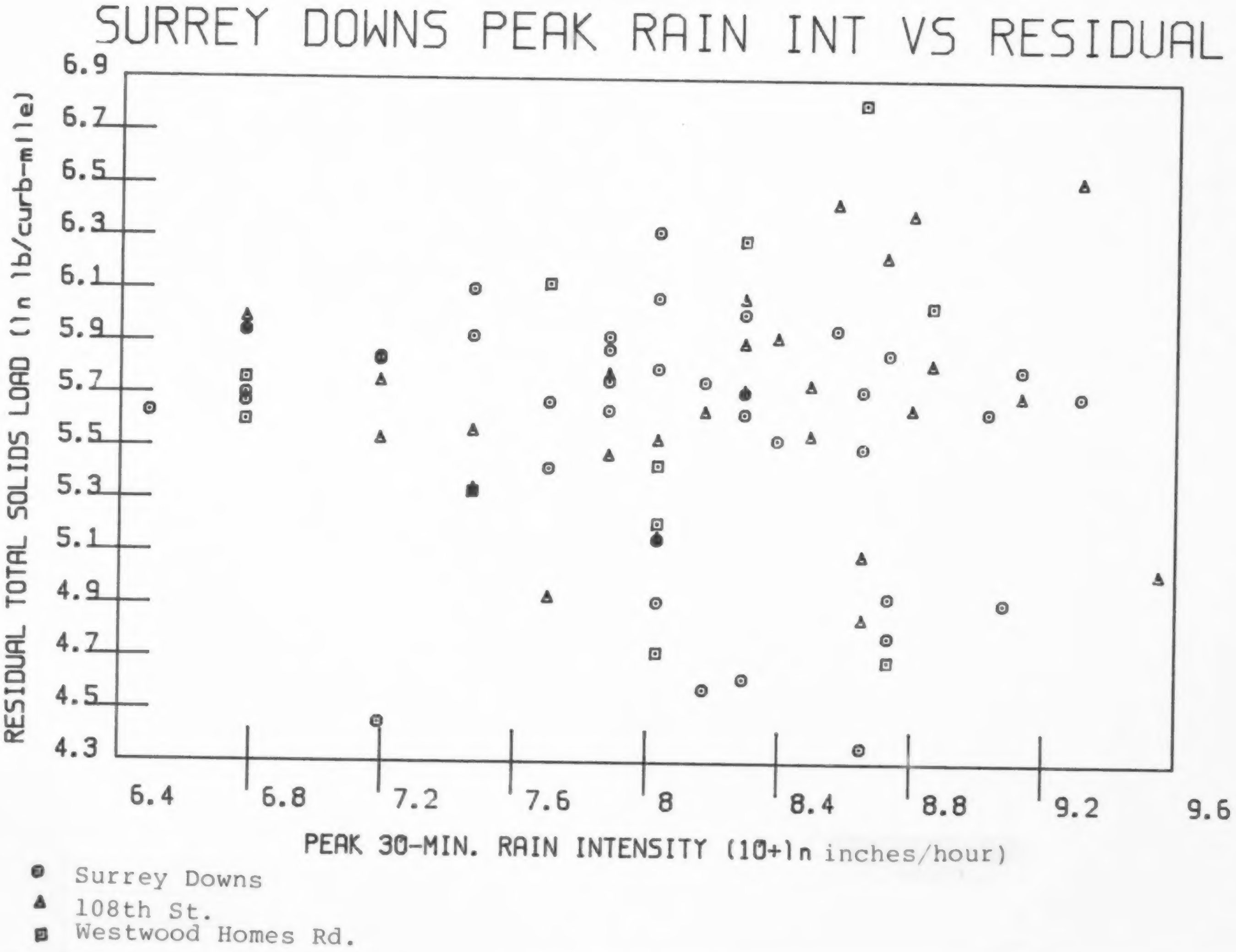
SURREY DOWNS PEAK RAIN INT VS RESIDUAL
RESIDUAL TOTAL SOLIDS LOAD (ln lb/curb-mile)
6.9
6.7
6.5
6.3
6.1
5.9
5.7
5.5
5.3
5.1
4.9
4.7
4.5
4.3
6.4
6.8
7.2
7.6
8
8.4
8.8
9.2
9.6
PEAK 30-MIN. RAIN INTENSITY (10+ln inches/hour)
Surrey Downs
108th St.
Westwood Homes Rd.

FIGURE B-15

LAKE HILLS & 148th PEAK RAIN VS RESIDUAL

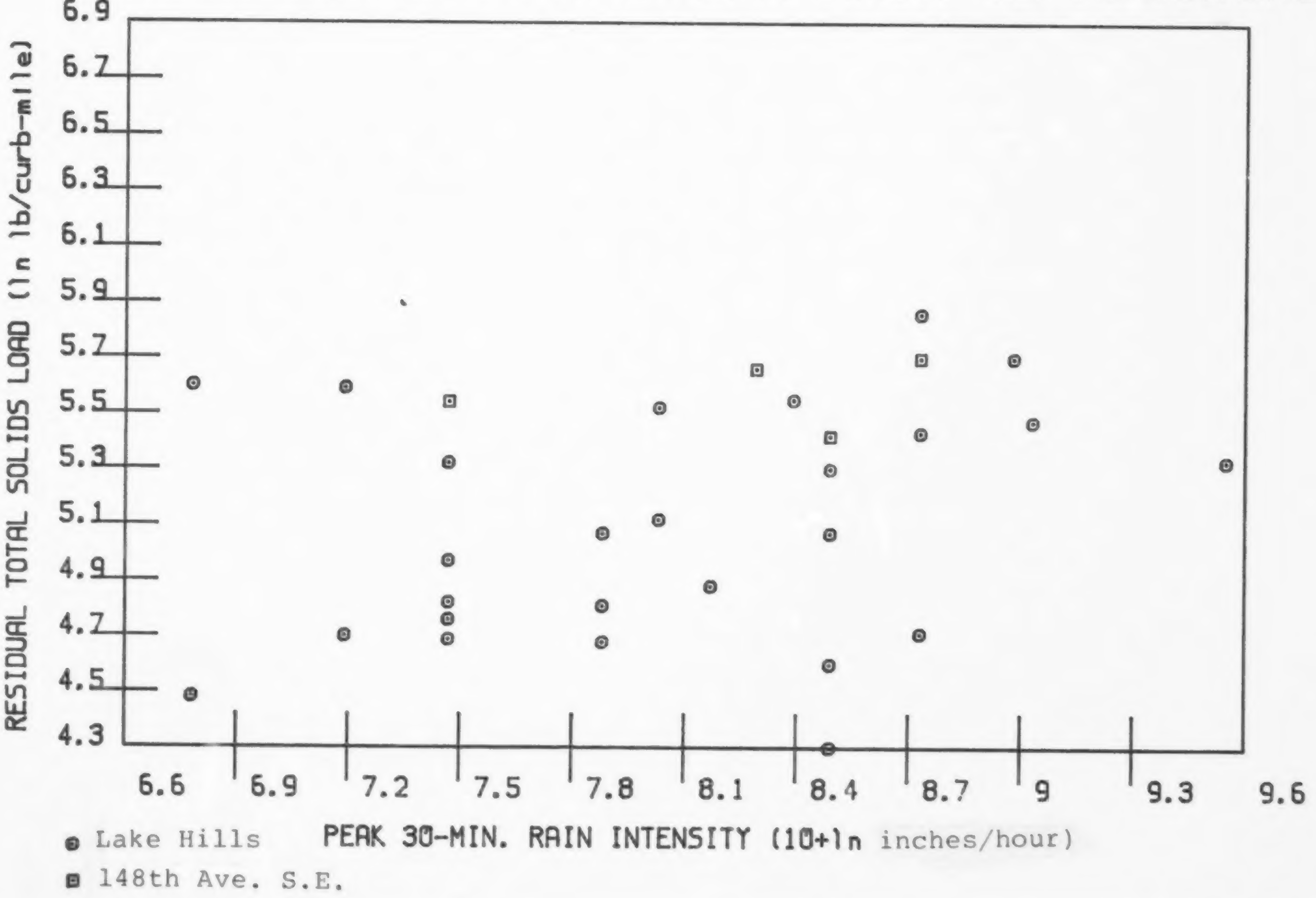

FIGURE B-16

LAKE HILLS STORM WASHOFF: <63 microns

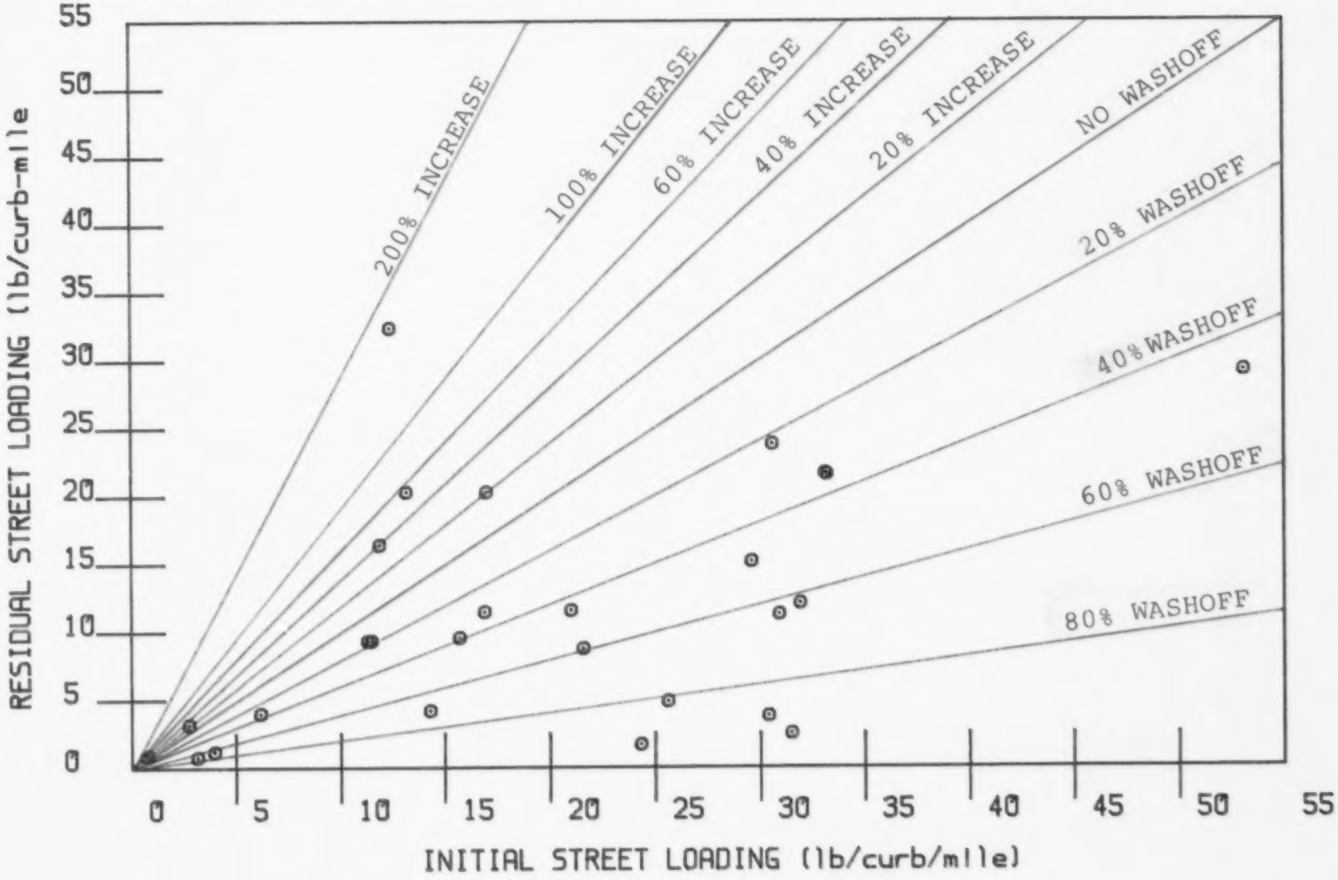

FIGURE B-17

LAKE HILLS STORM WASHOFF: 63-125 microns

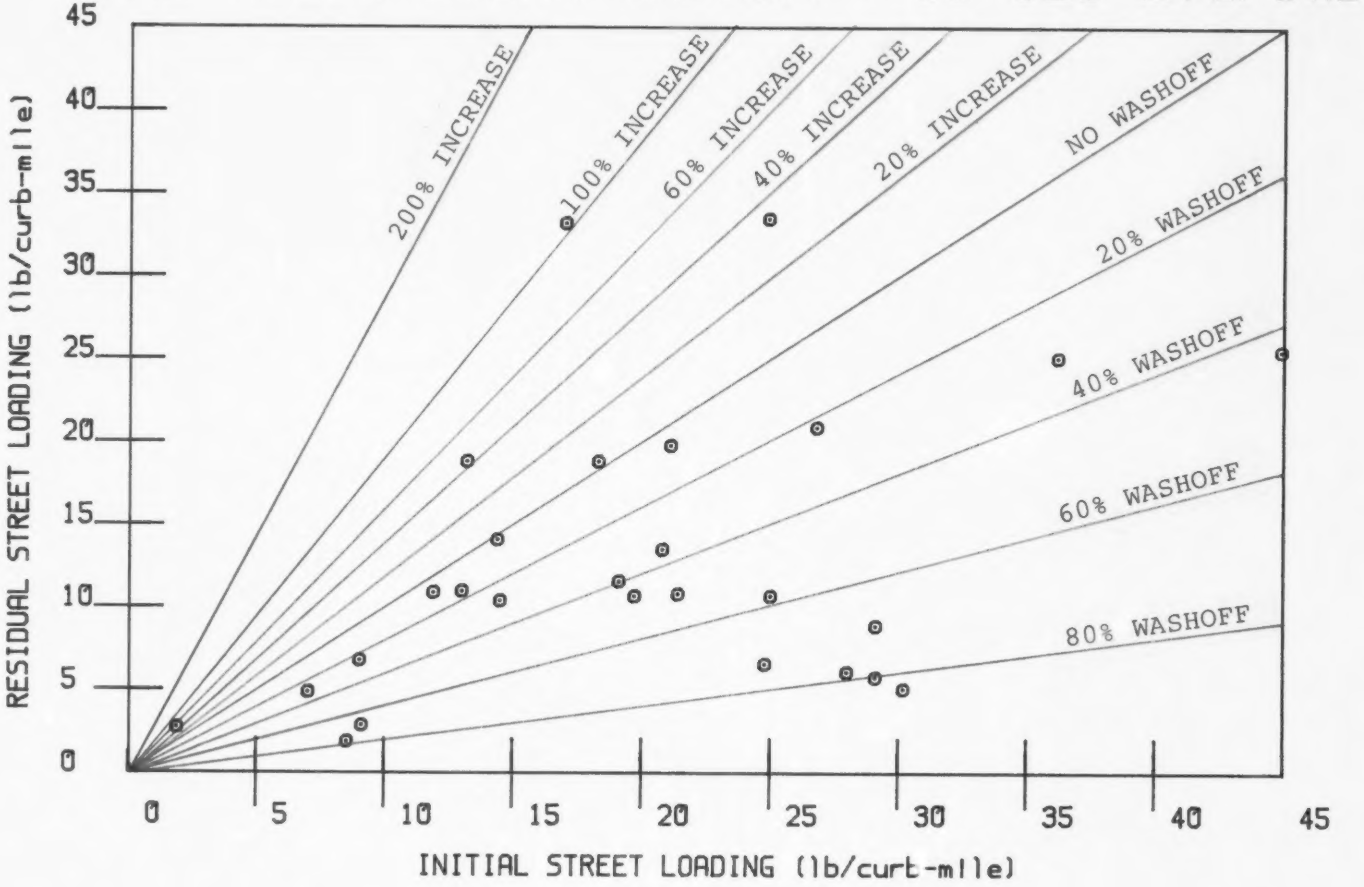

FIGURE B-18

LAKE HILLS STORM WASHOFF: 125-250 microns

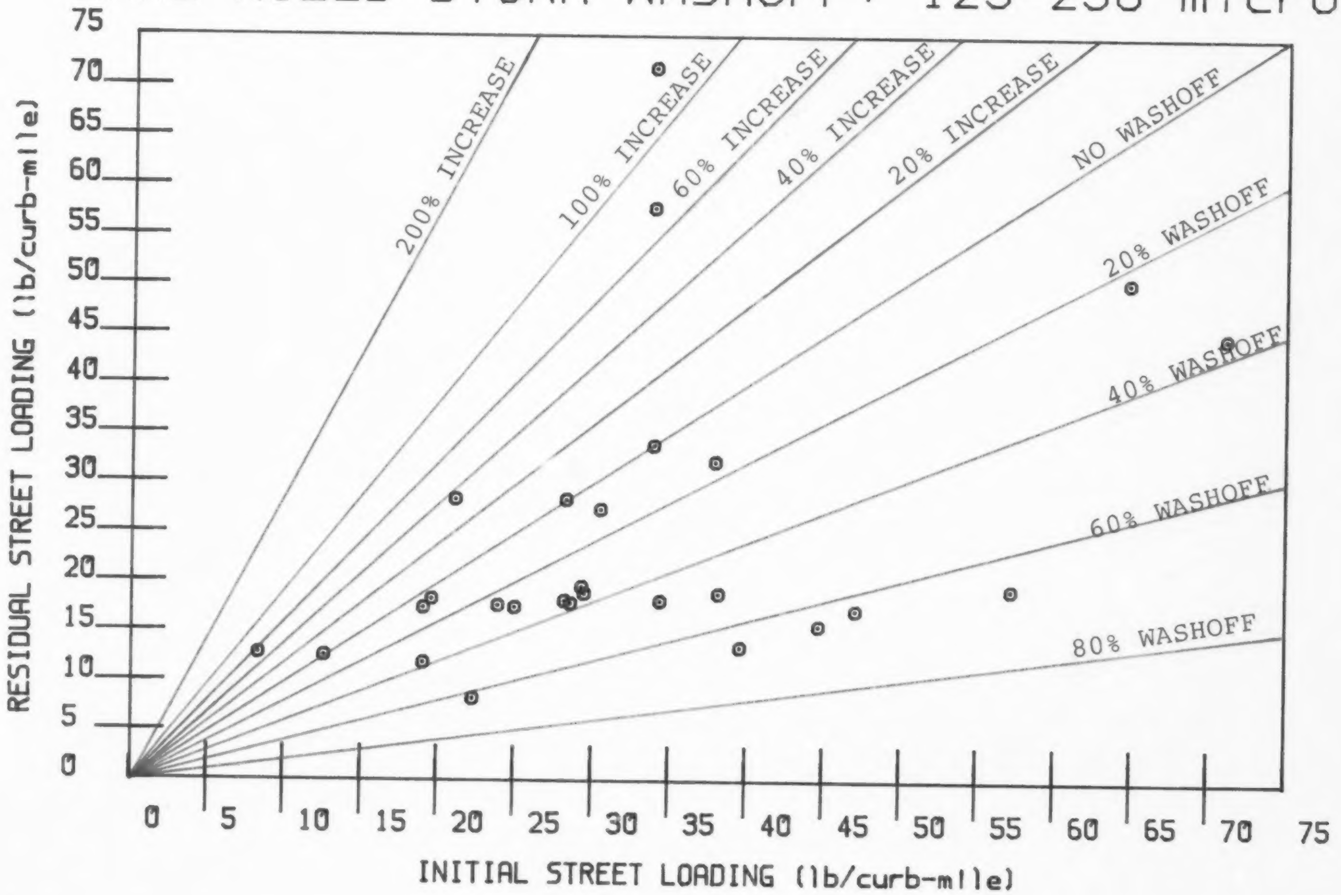

FIGURE B-19

LAKE HILLS STORM WASHOFF: 250-500 microns

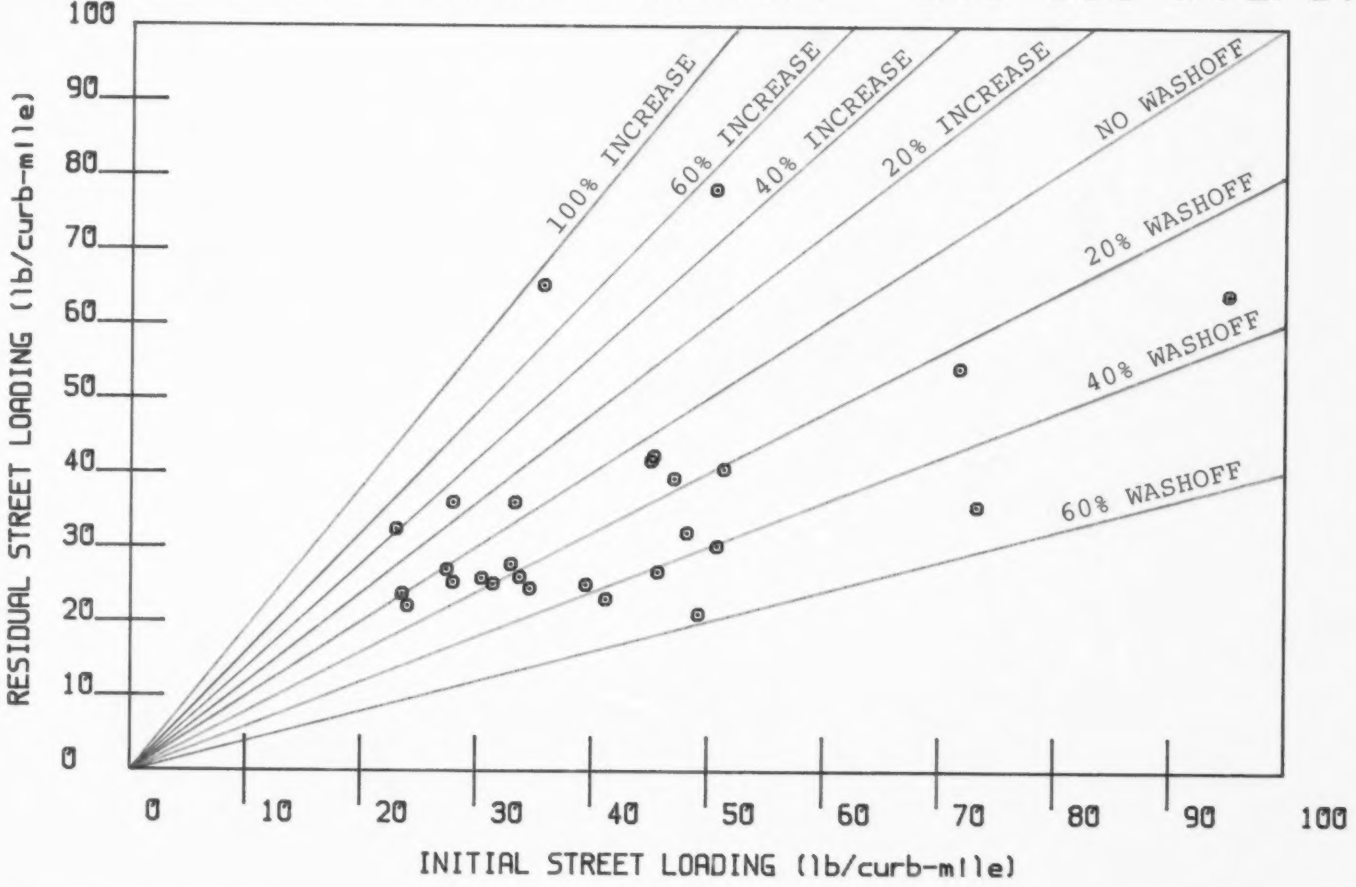

FIGURE B-20

LAKE HILLS STORM WASHOFF: 500-1000 microns

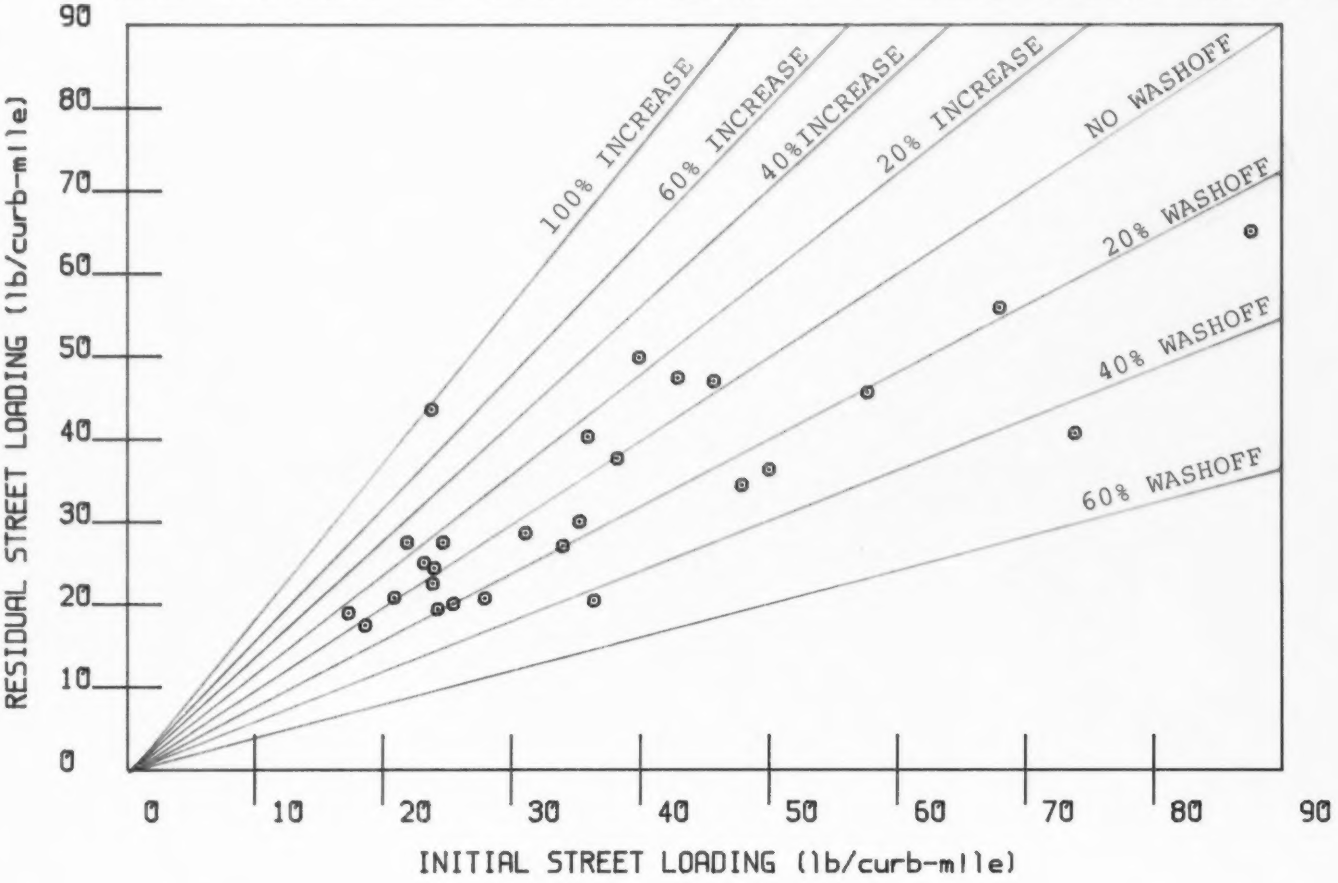

FIGURE B-21

LAKE HILLS STORM WASHOFF: 1000-2000 microns

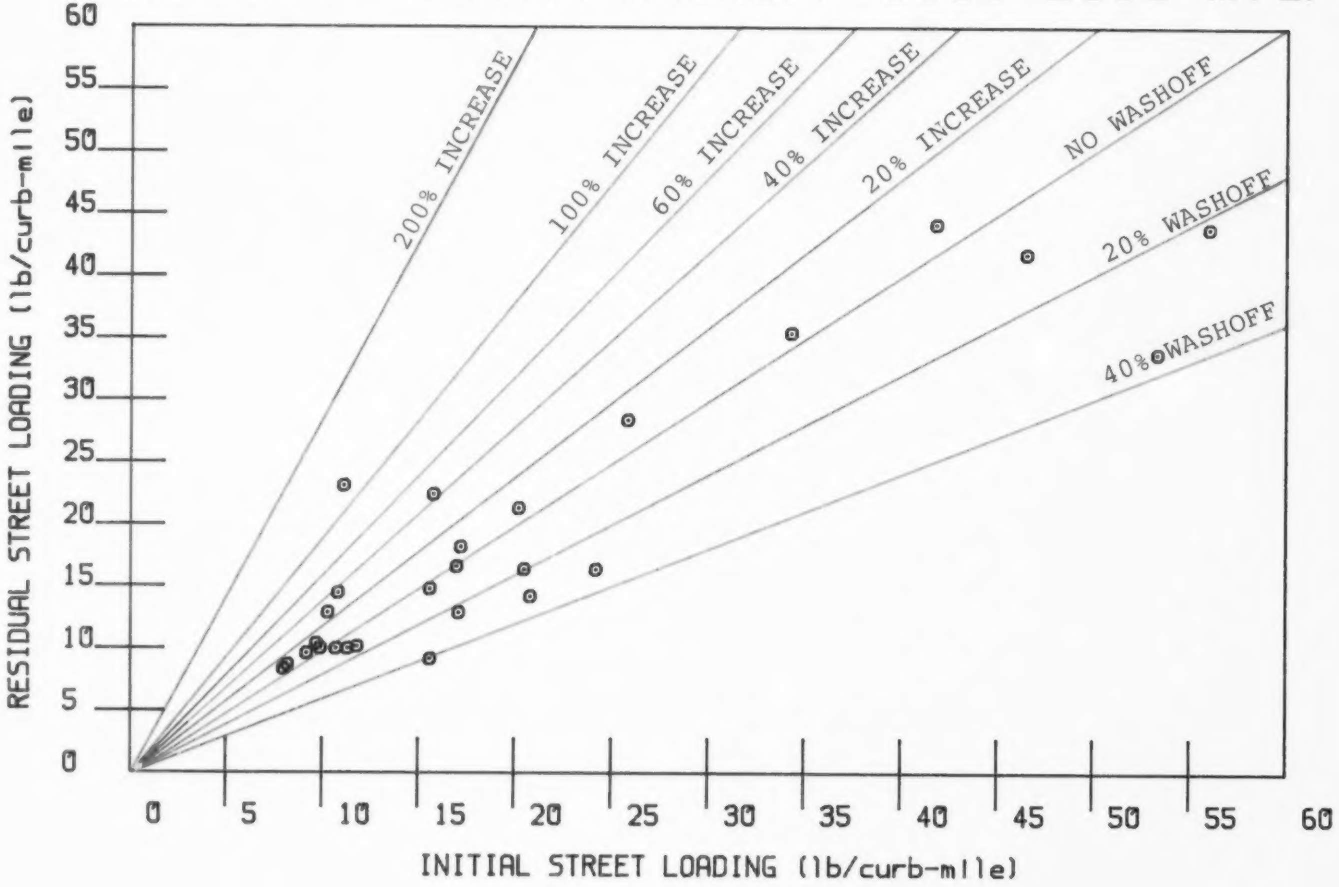

FIGURE B-22

LAKE HILLS STORM WASHOFF: 2000-6350 microns

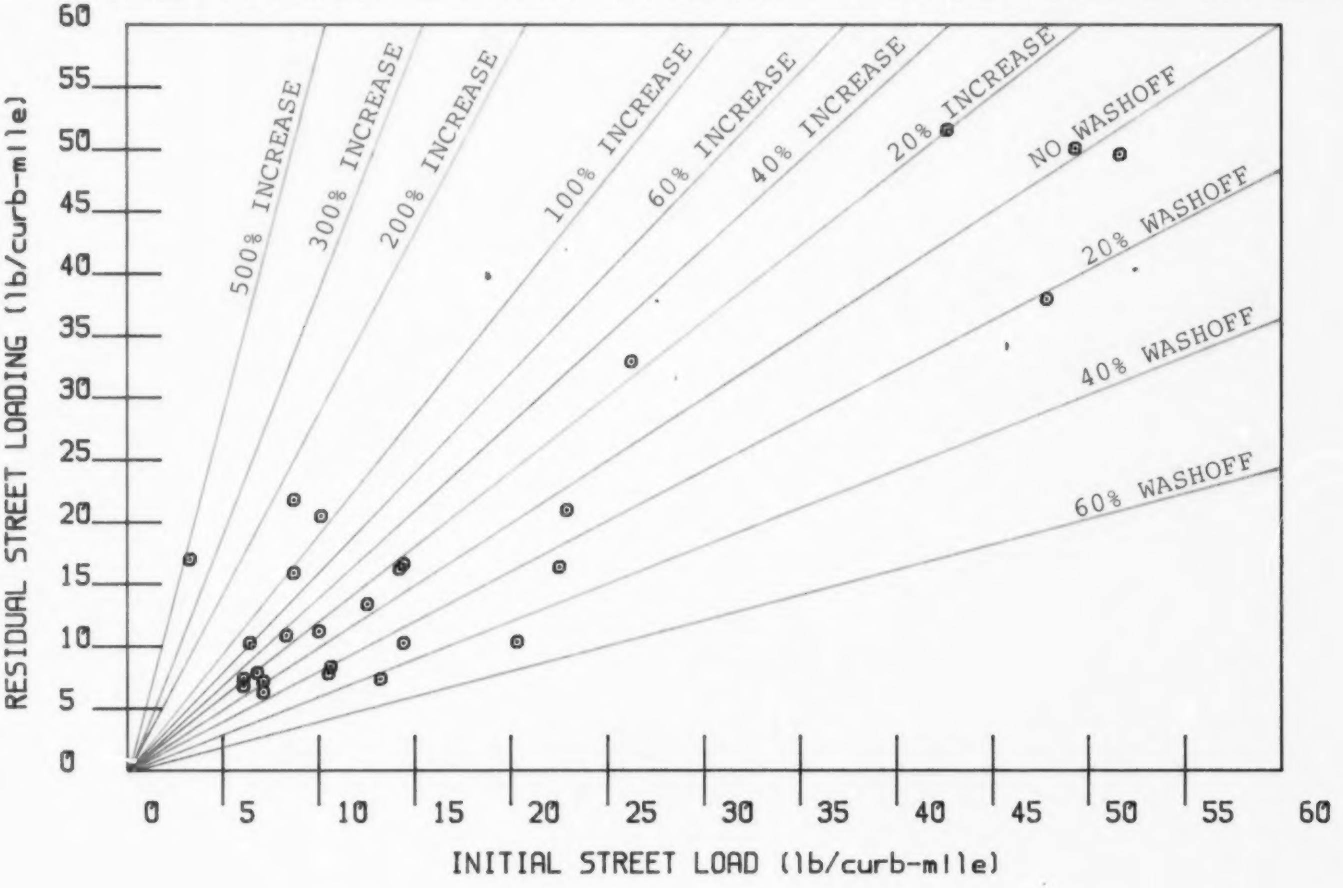

FIGURE B-23

LAKE HILLS STORM WASHOFF: >6350 microns

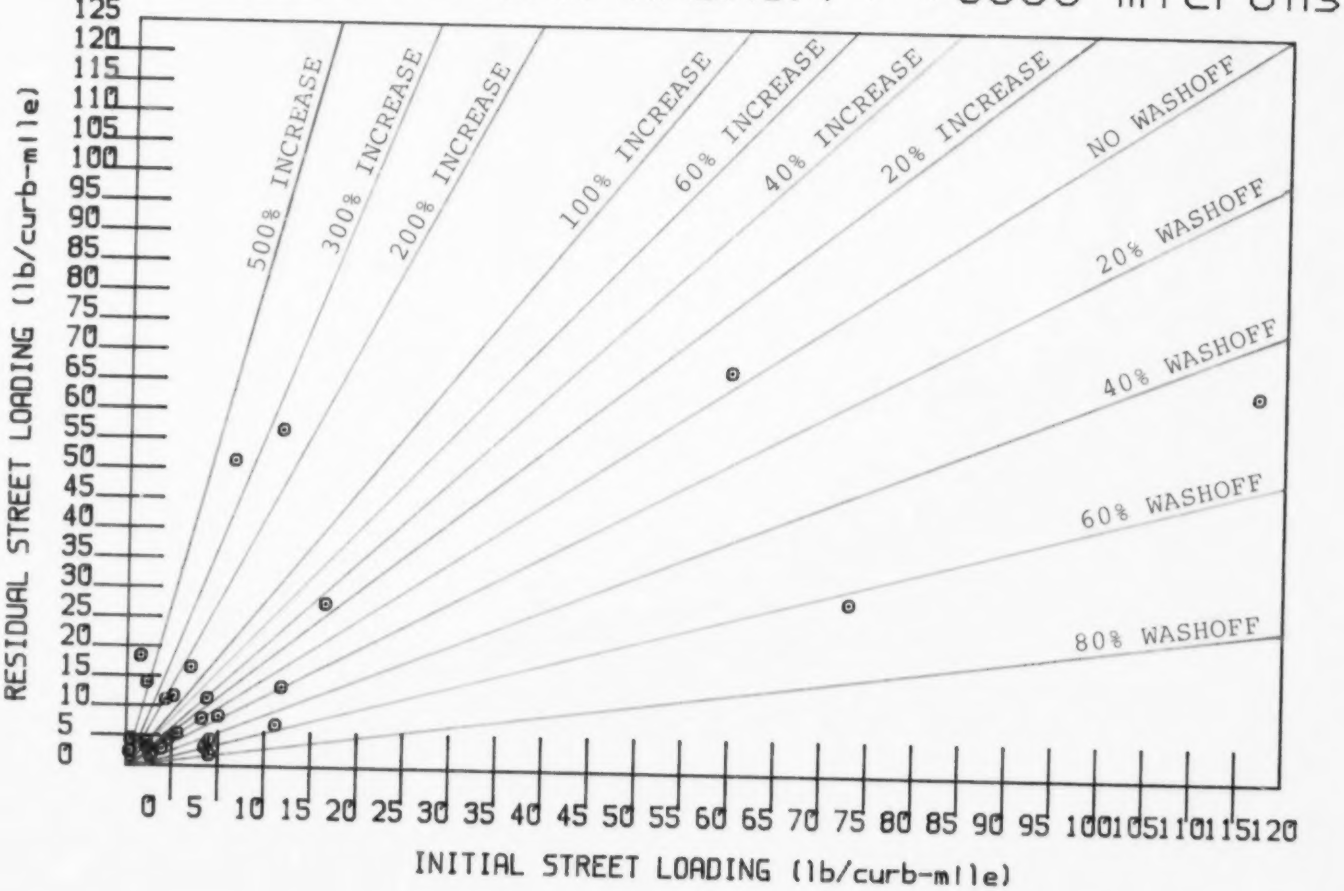

FIGURE B-24

SURREY DOWNS TOTAL SOLIDS - WET SEASON

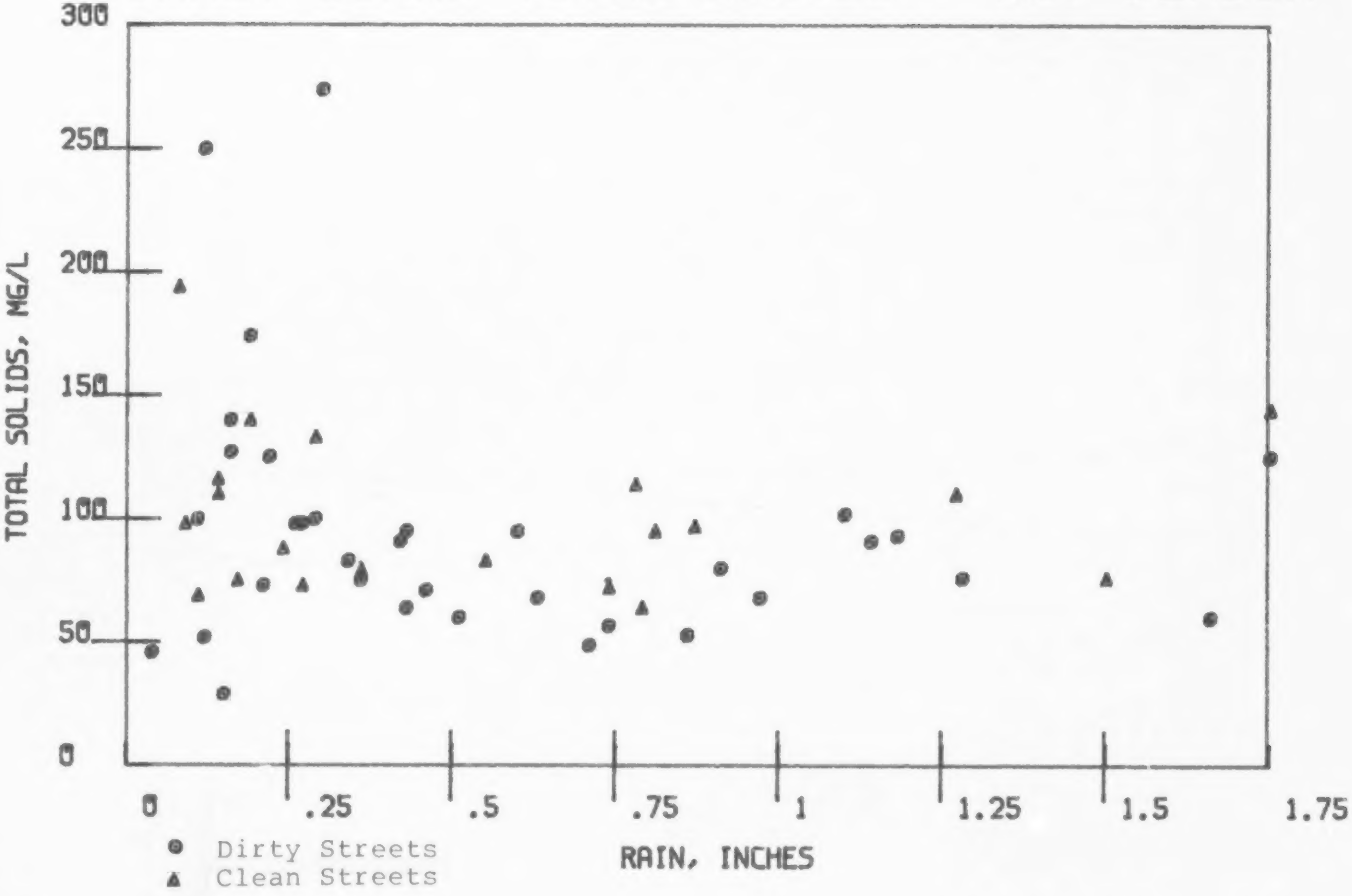

FIGURE B-25

SURREY DOWNS TOTAL SOLIDS - DRY SEASON

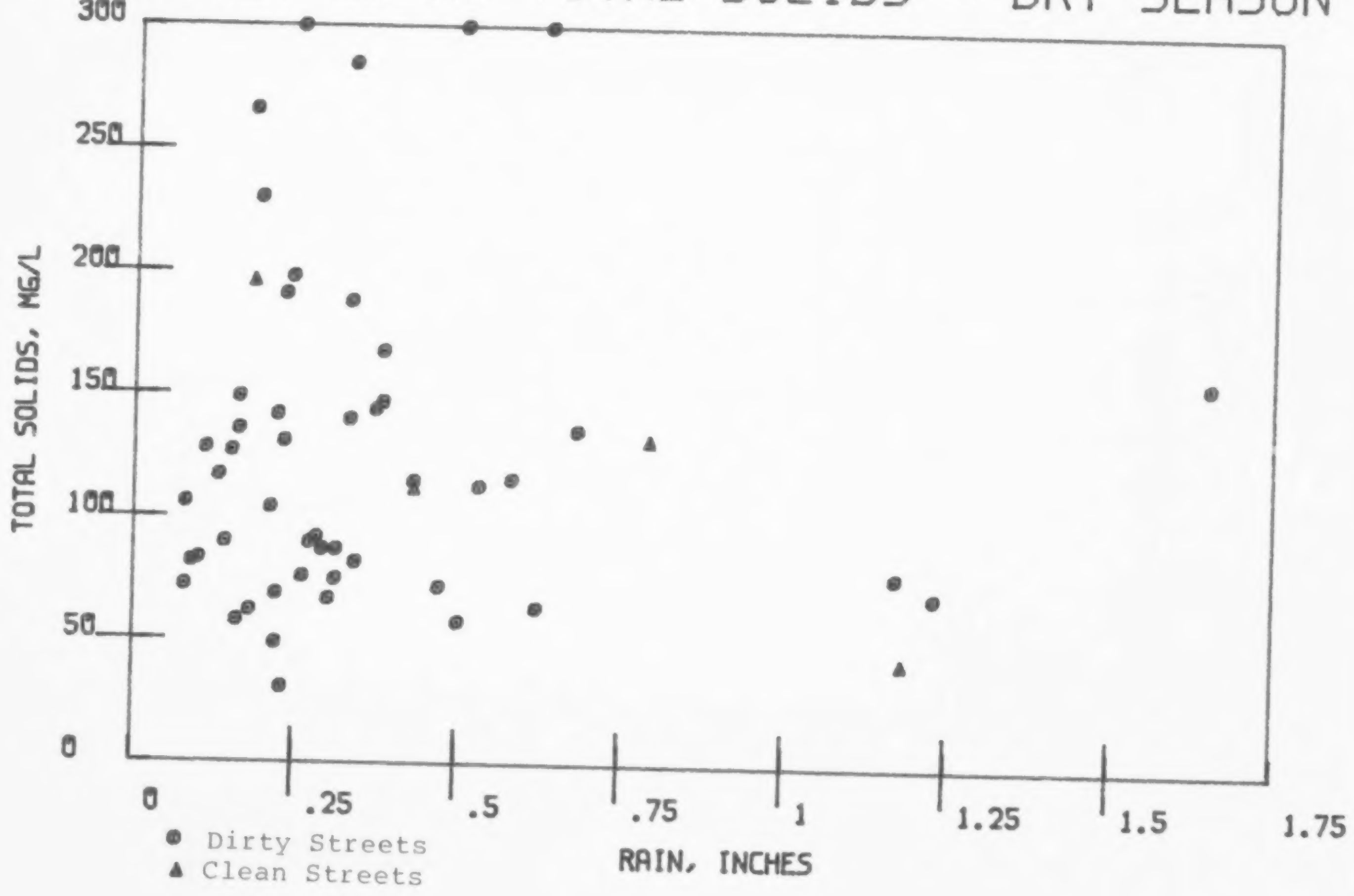

FIGURE B-26

LAKE HILLS TOTAL SOLIDS - WET SEASON

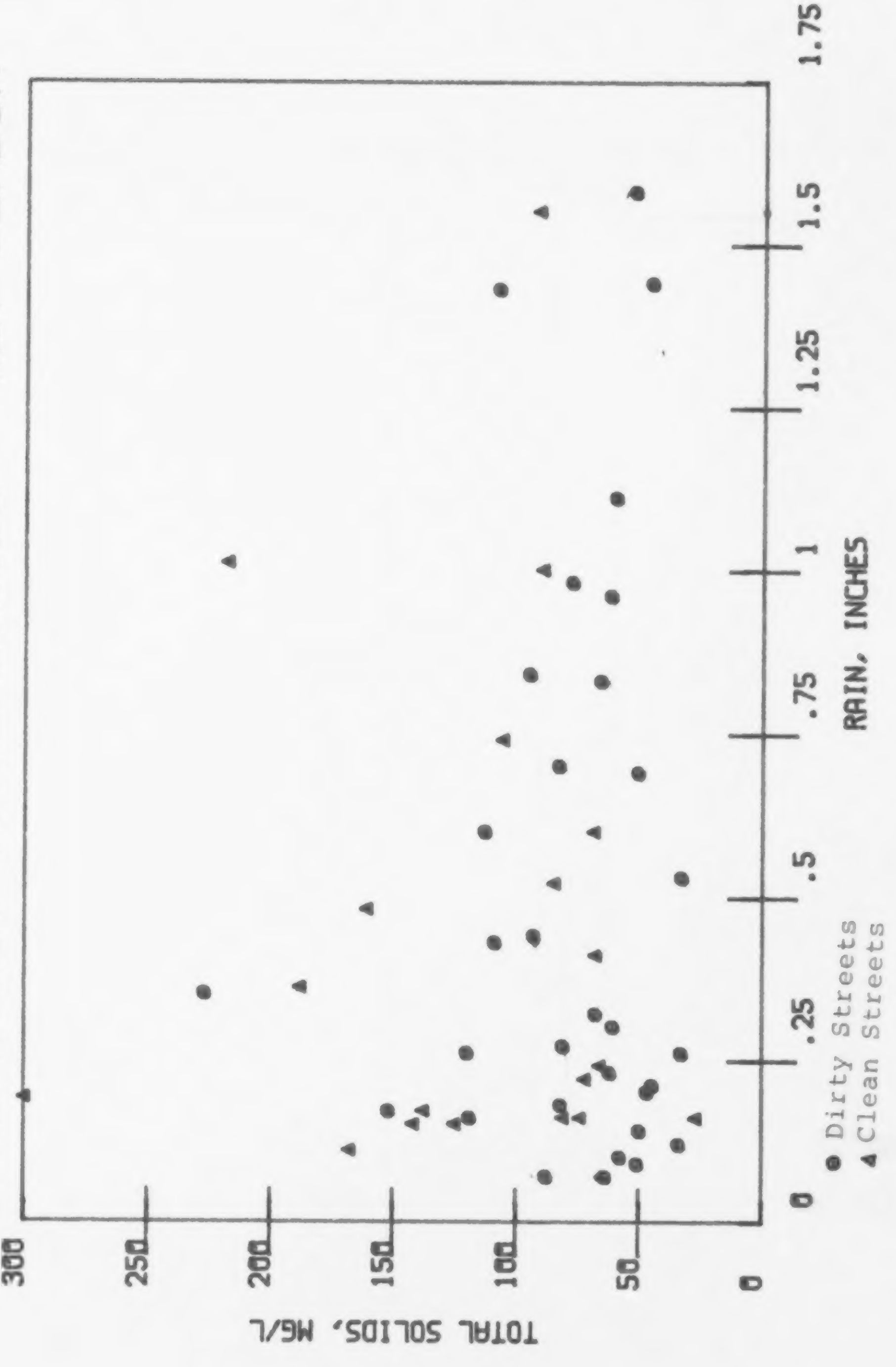

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FIGURE B-27

LAKE HILLS TOTAL SOLIDS - DRY SEASON

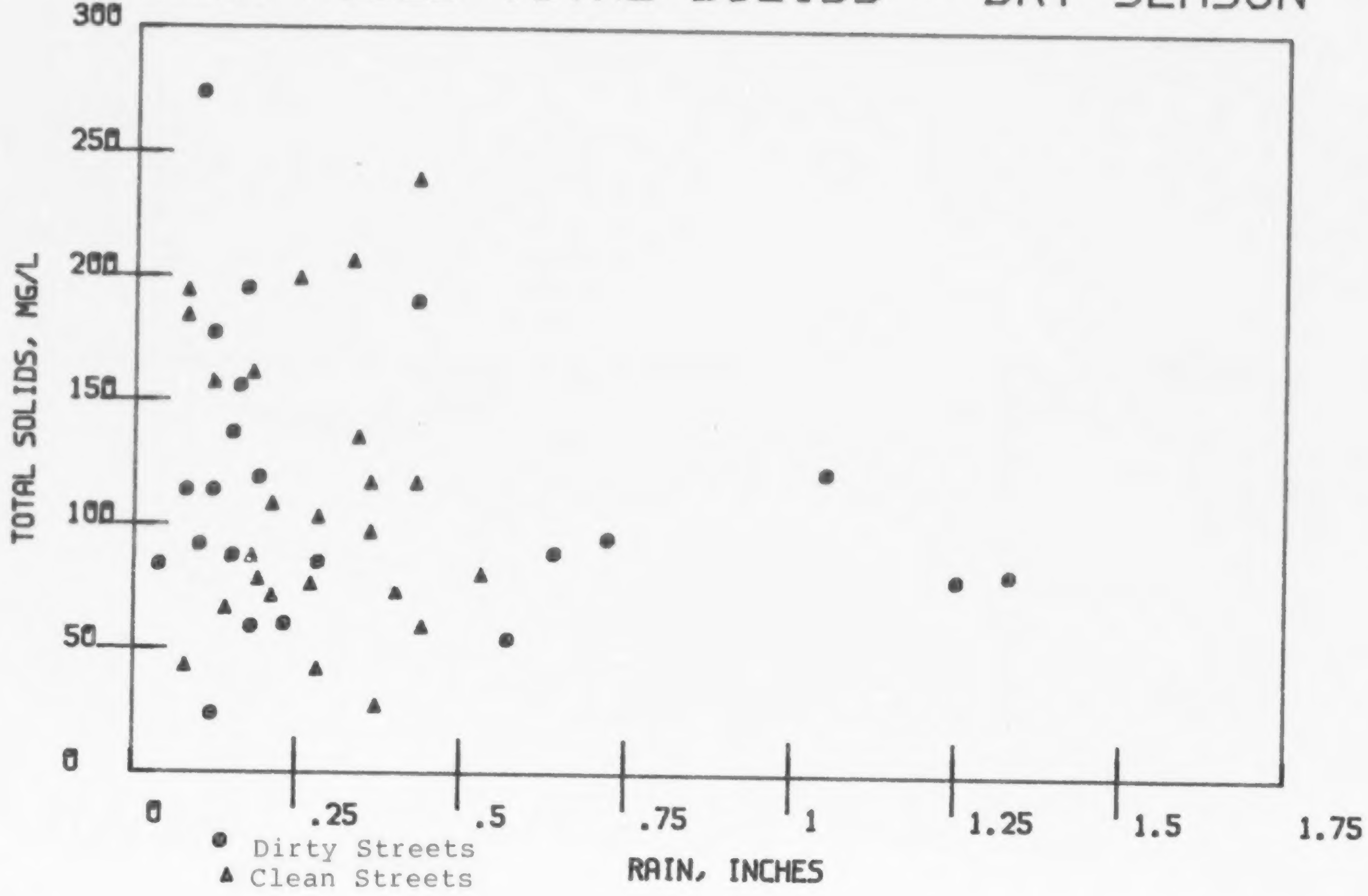

FIGURE B-28

SURREY DOWNS LEAD - WET SEASON

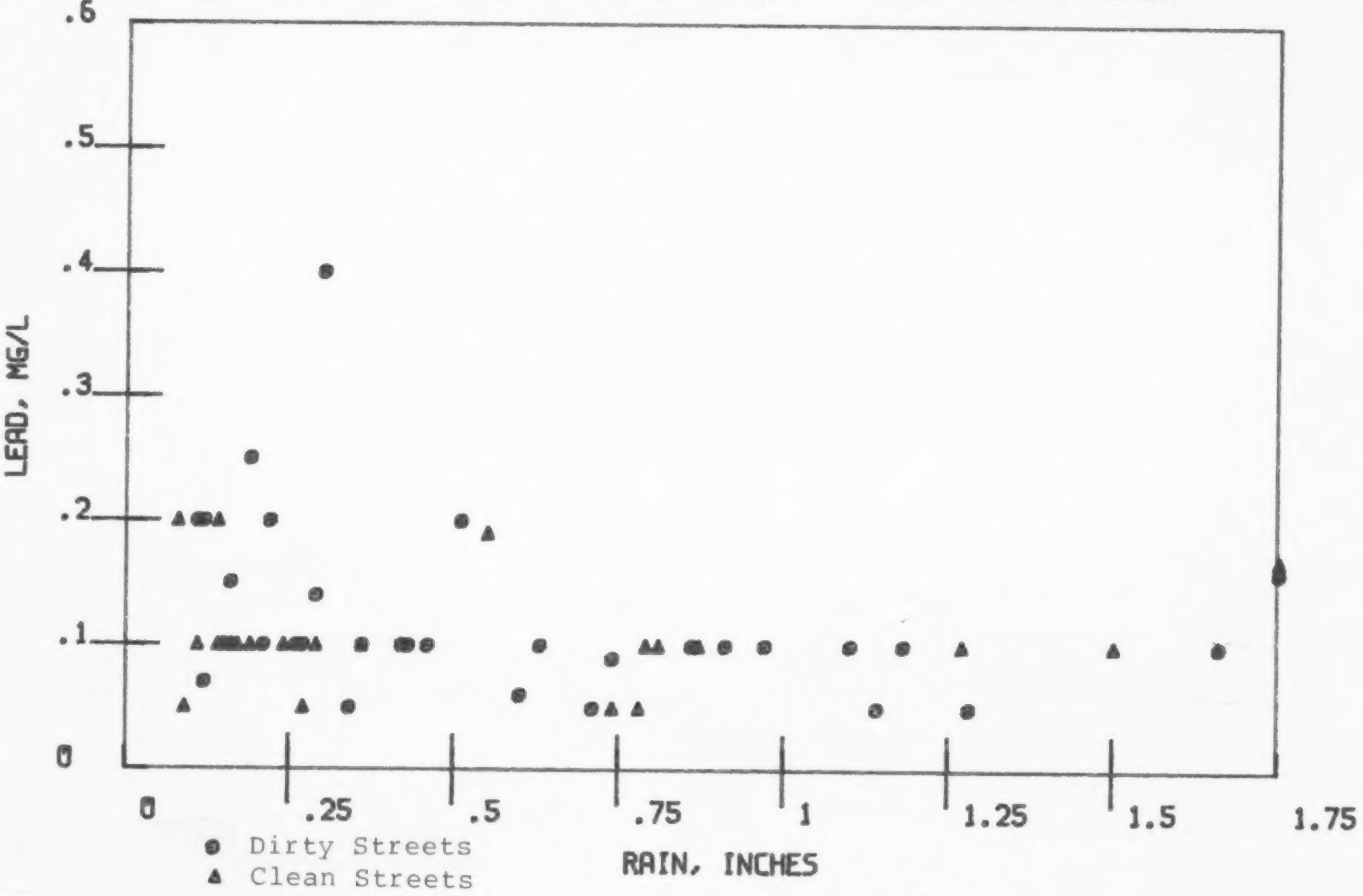

FIGURE B-29

SURREY DOWNS LEAD - DRY SEASON

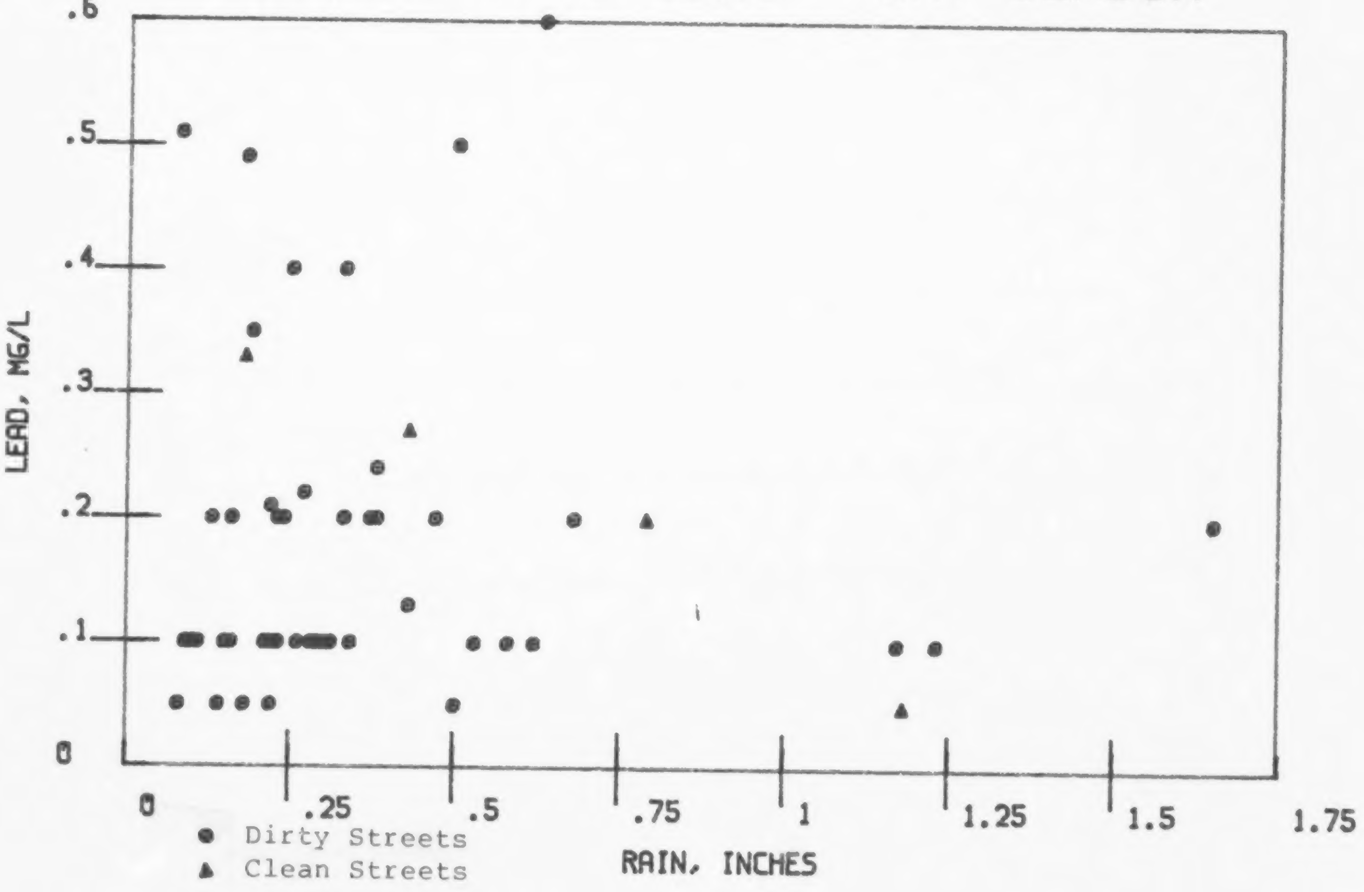

FIGURE B-30

LAKE HILLS LEAD - WET SEASON

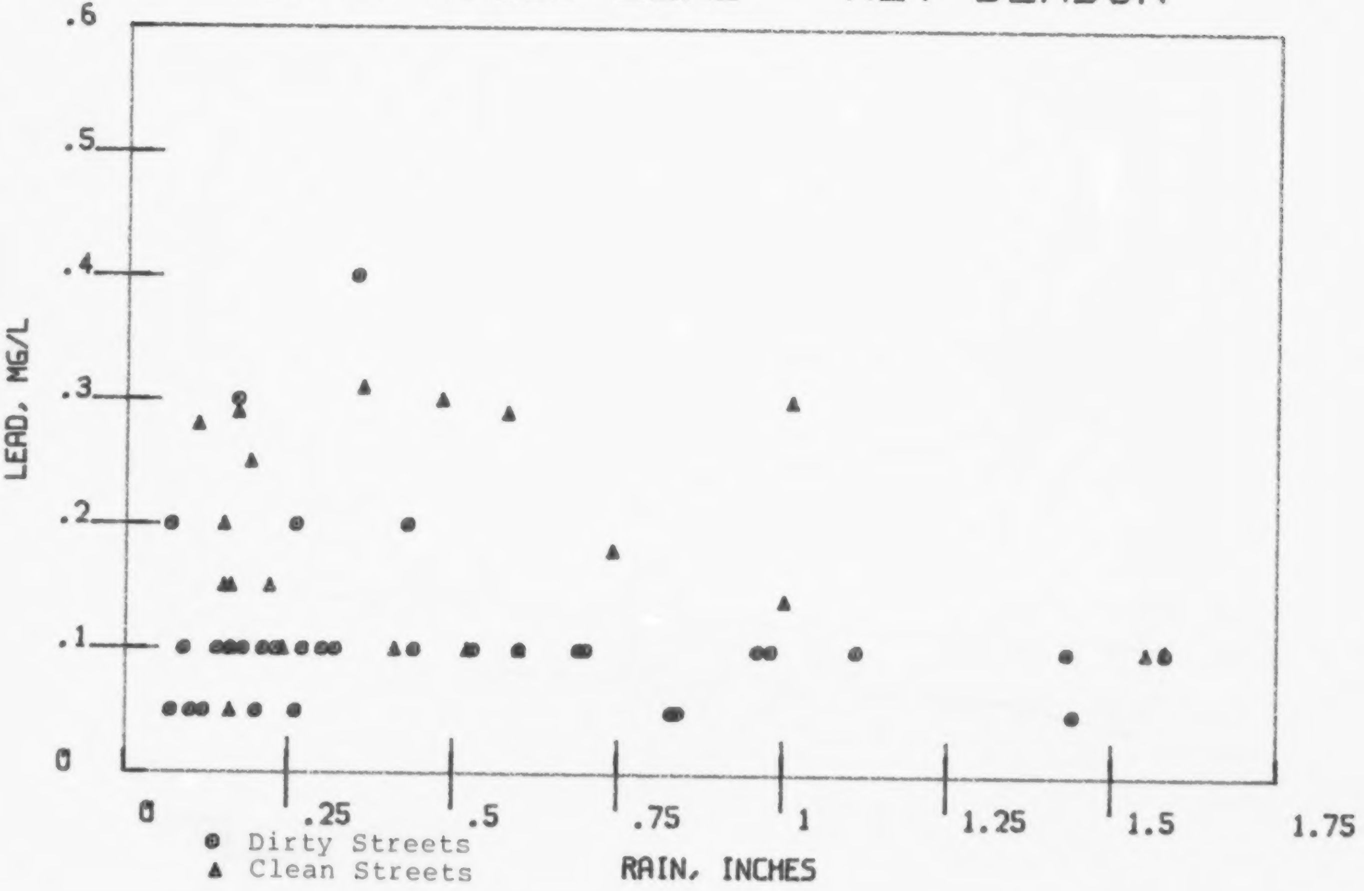

FIGURE B-31

LAKE HILLS LEAD - DRY SEASON

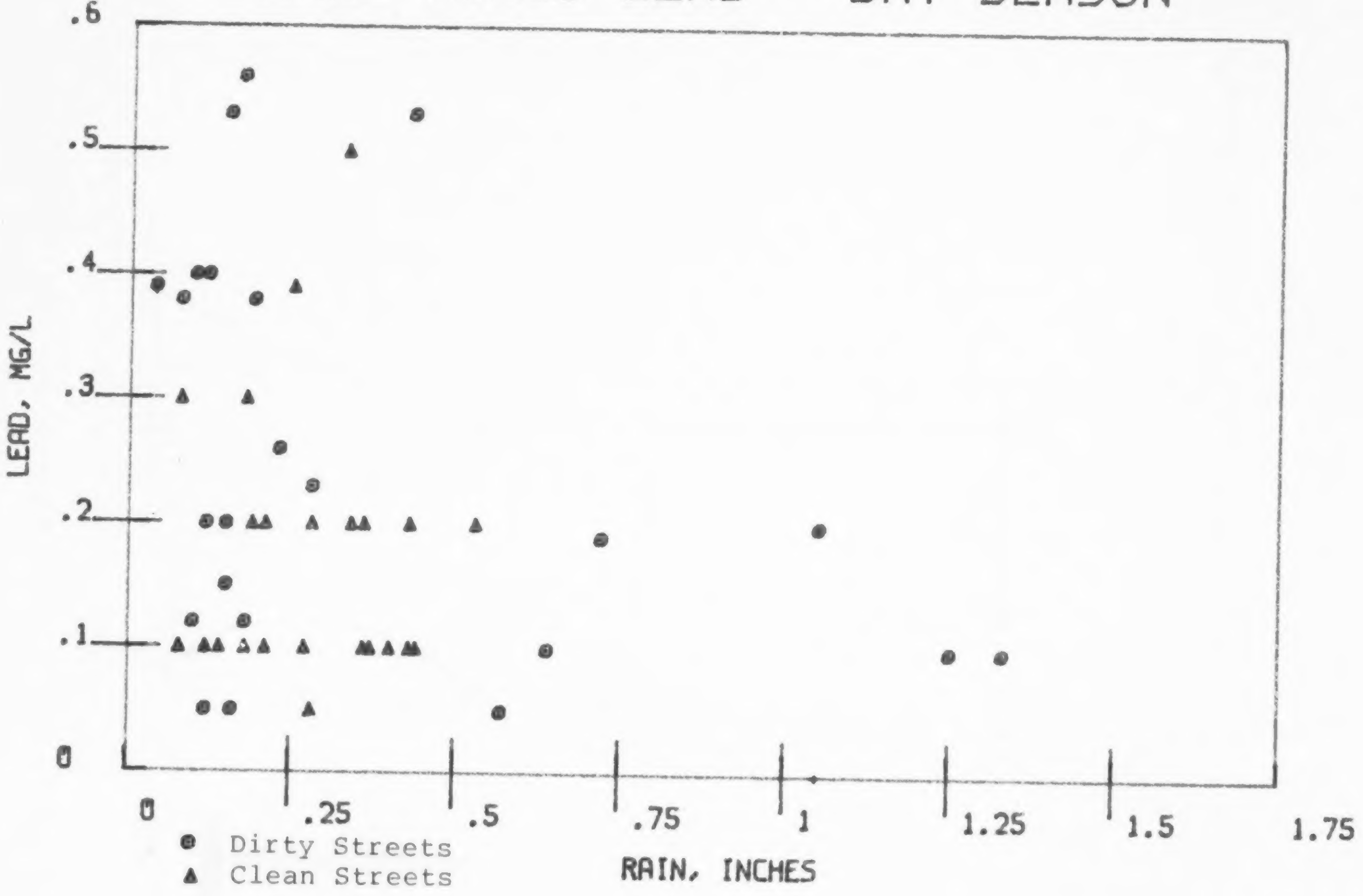

FIGURE B-32

WET SEASON TOTAL SOLIDS LOADS VS. RUNOFF

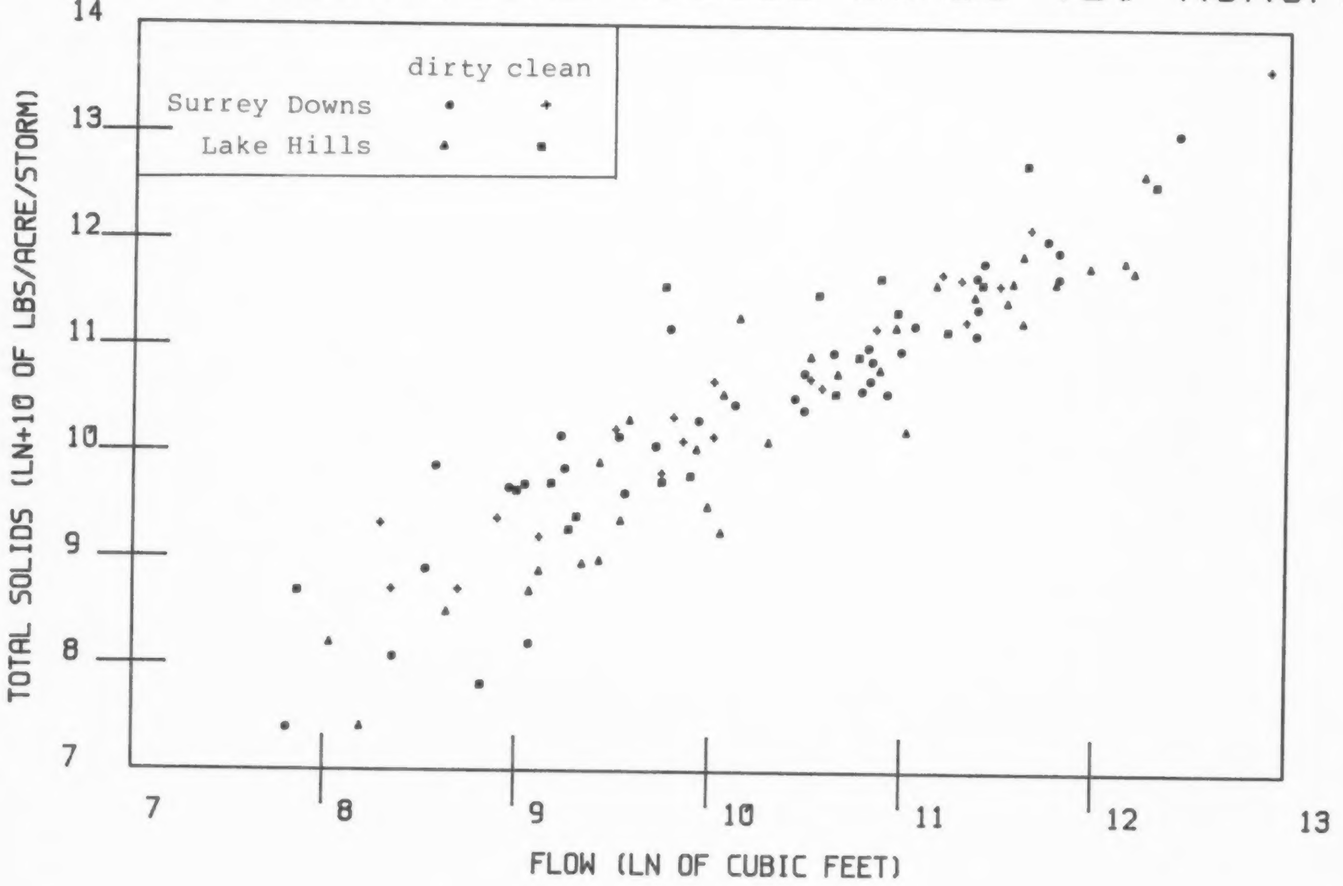

FIGURE B-33

DRY SEASON TOTAL SOLIDS LOADS VS. RUNOFF

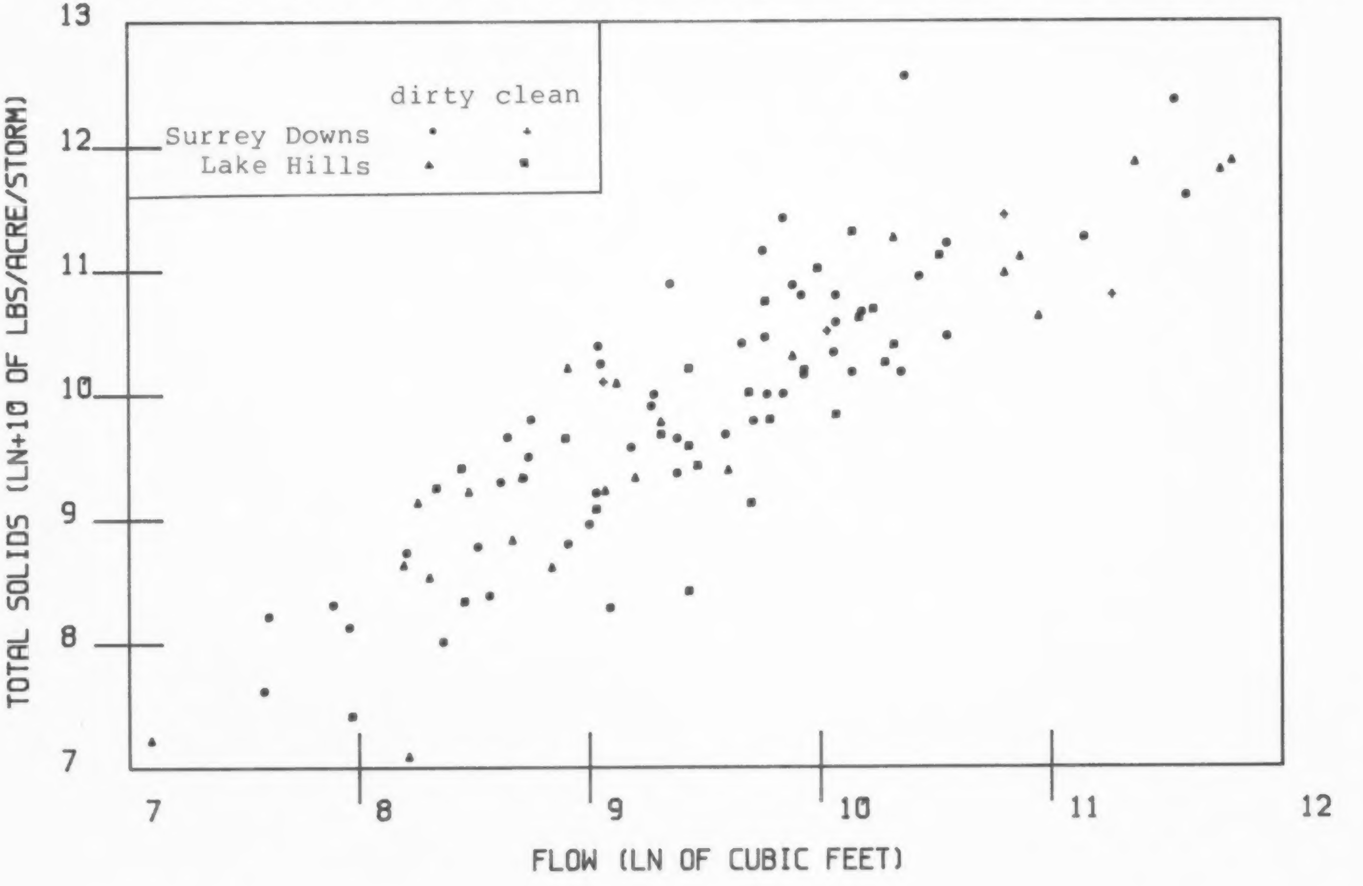

FIGURE B-34

WET SEASON LEAD YIELDS VS. RUNOFF

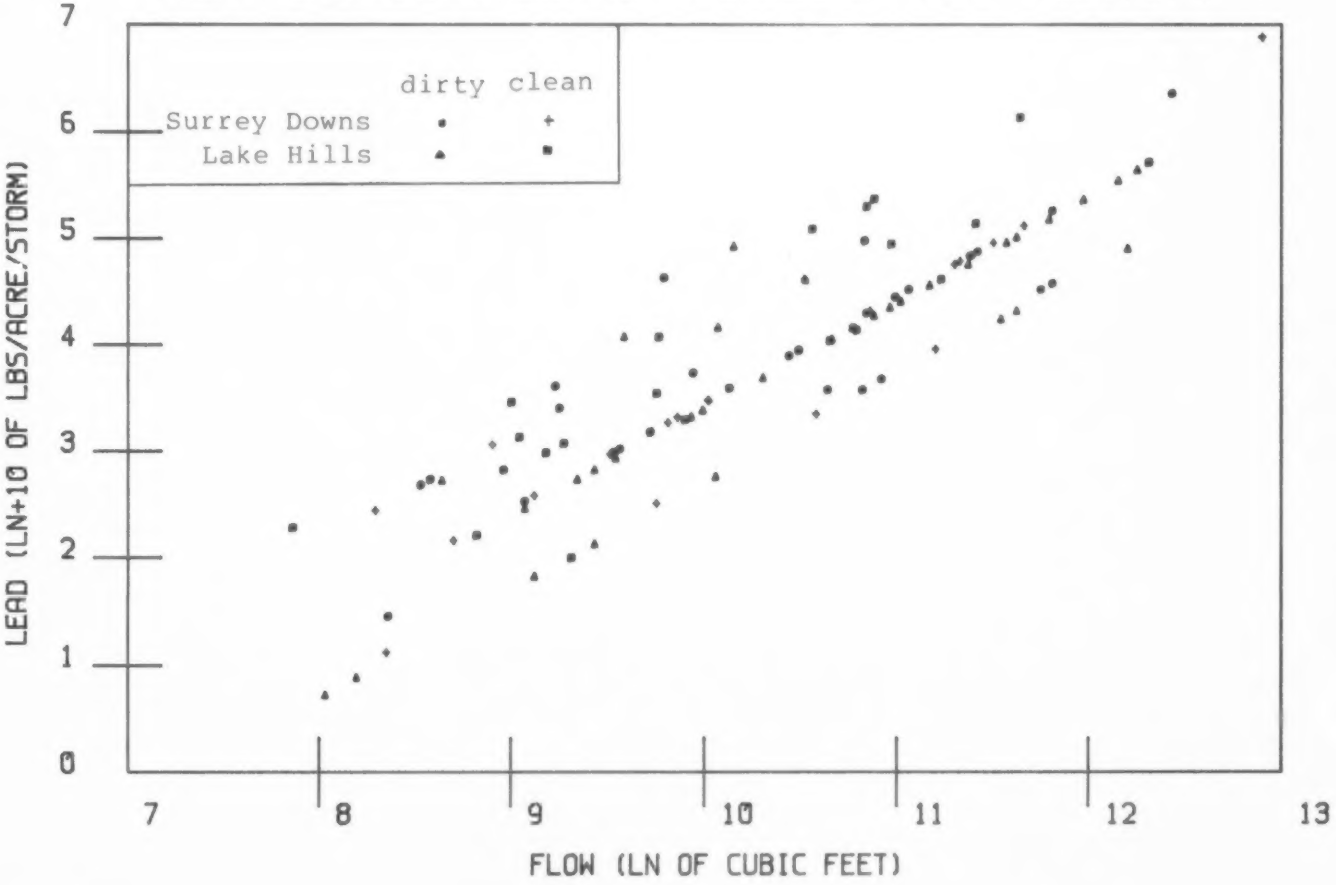

FIGURE B-35

DRY SEASON LEAD YIELDS VS. RUNOFF

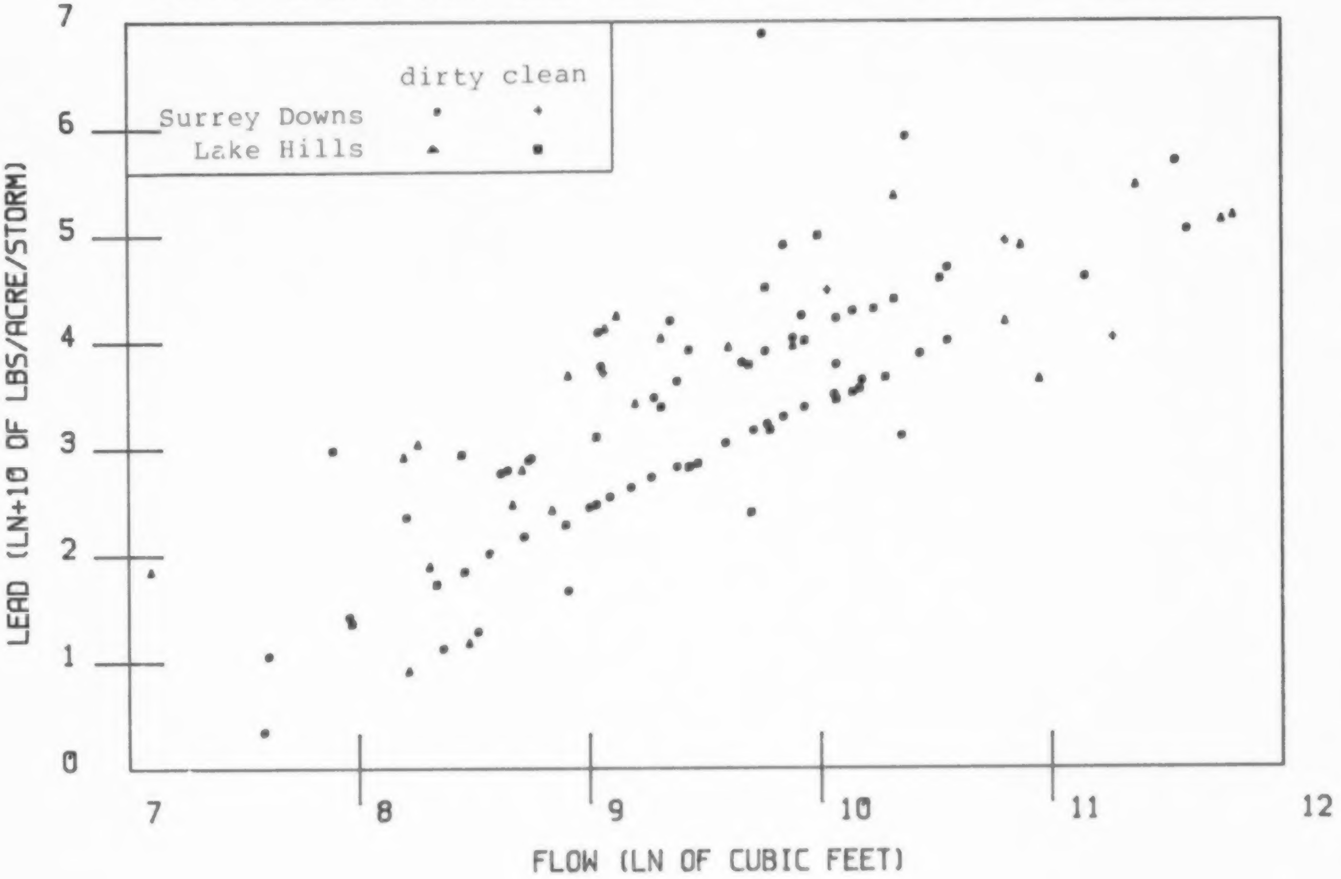

FIGURE B-36

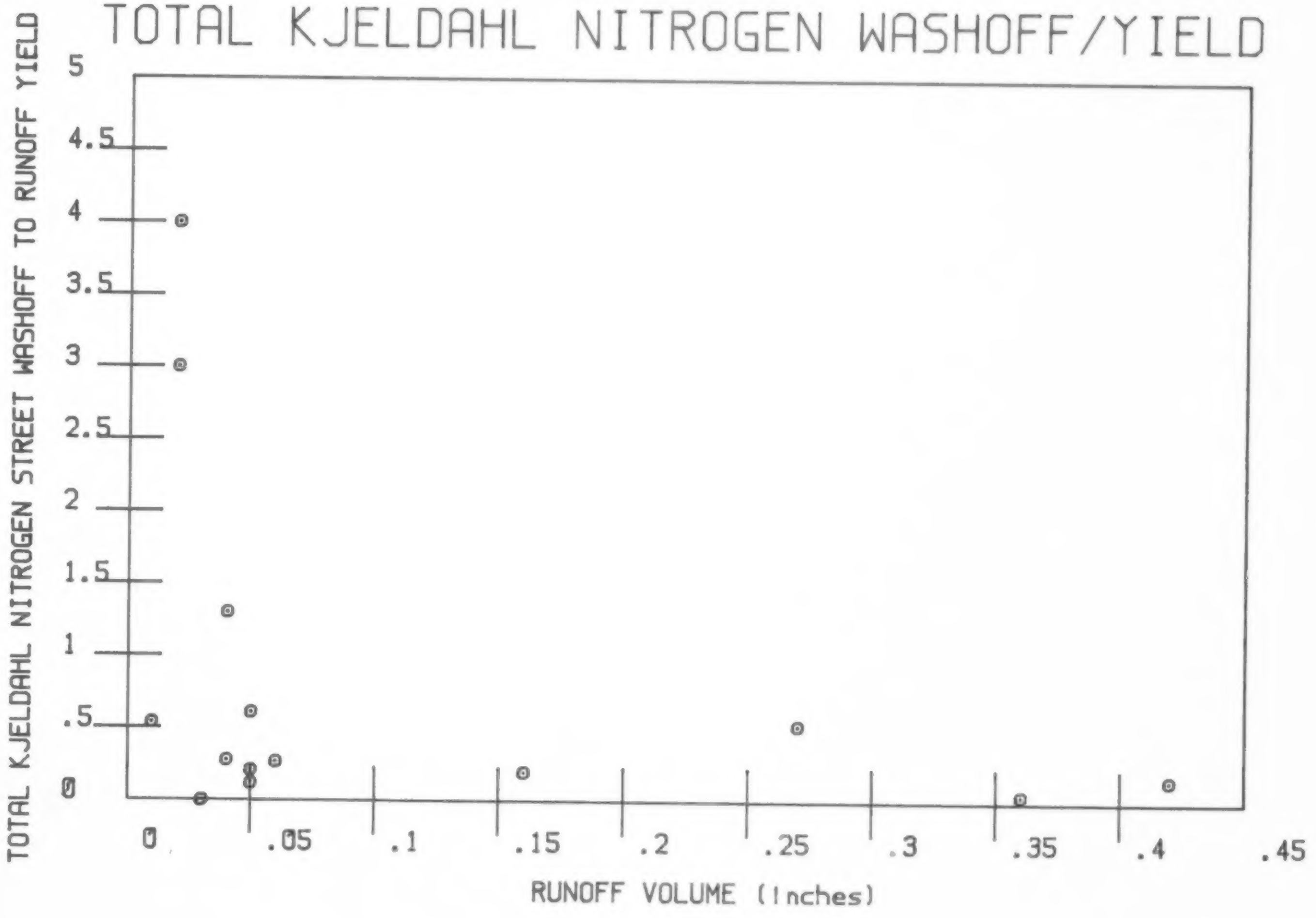
TOTAL KJELDAHL NITROGEN WASHOFF/YIELD
TOTAL KJELDAHL NITROGEN STREET WASHOFF TO RUNOFF YIELD
5
4.5
4
3.5
3
2.5
2
1.5
1
.5
0
0
.05
.1
.15
.2
.25
.3
.35
.4
.45
RUNOFF VOLUME (Inches)

FIGURE B-37

COD STREET WASHOFF/RUNOFF YIELD RATIO

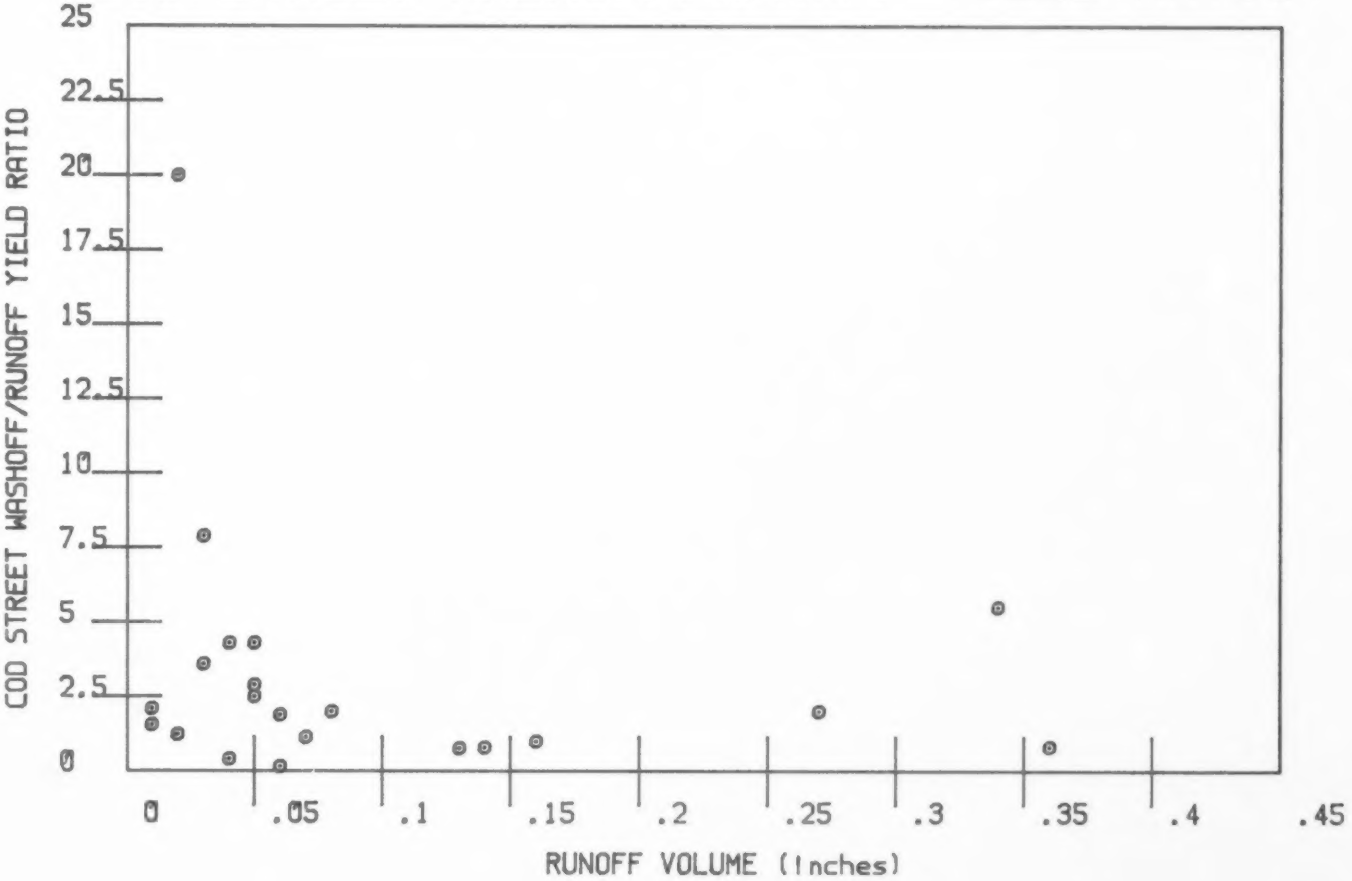

FIGURE B-38

PHOSPHORUS WASHOFF/RUNOFF RATIO

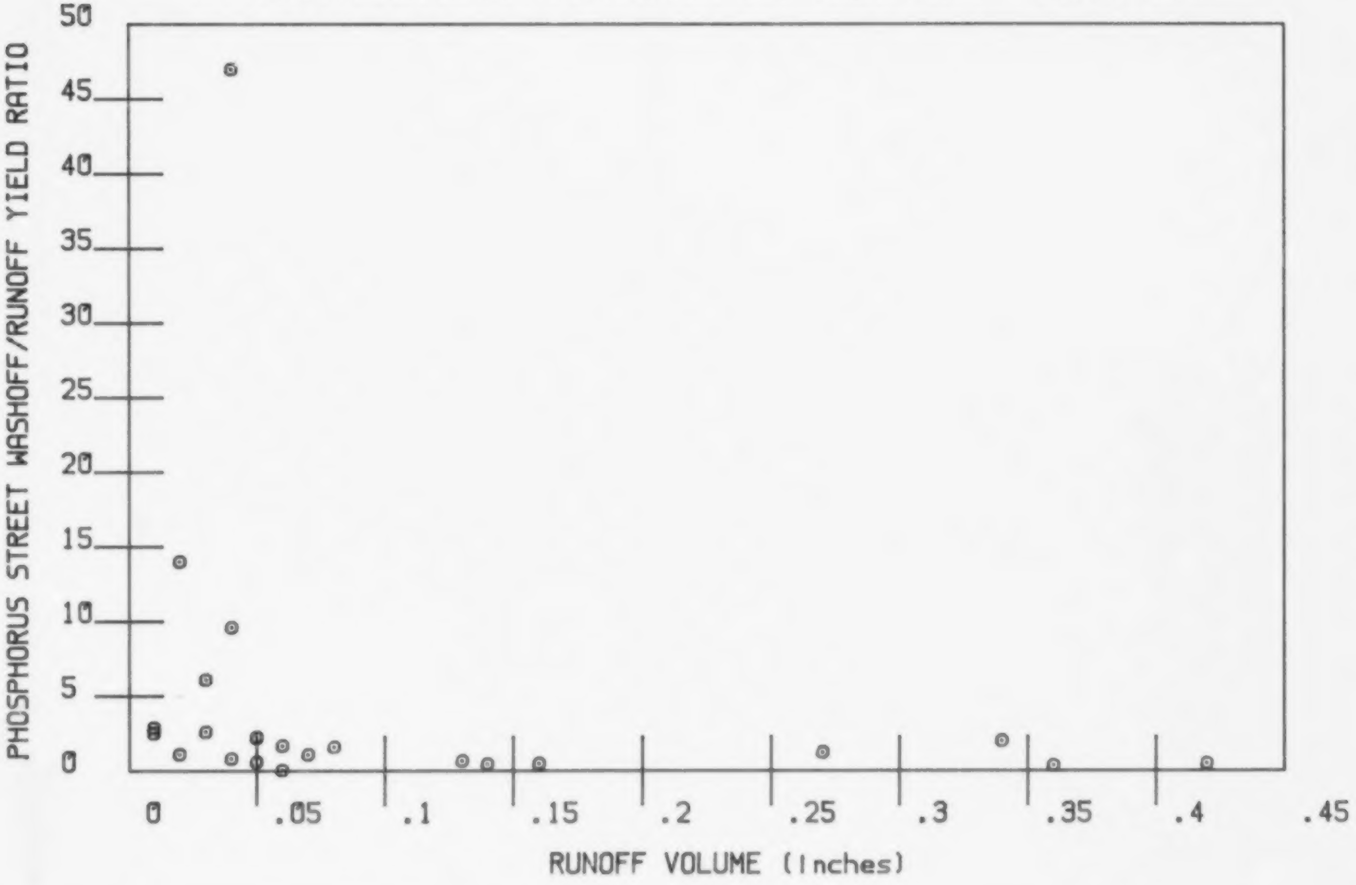

FIGURE B-39

ZINC WASHOFF/RUNOFF YIELD

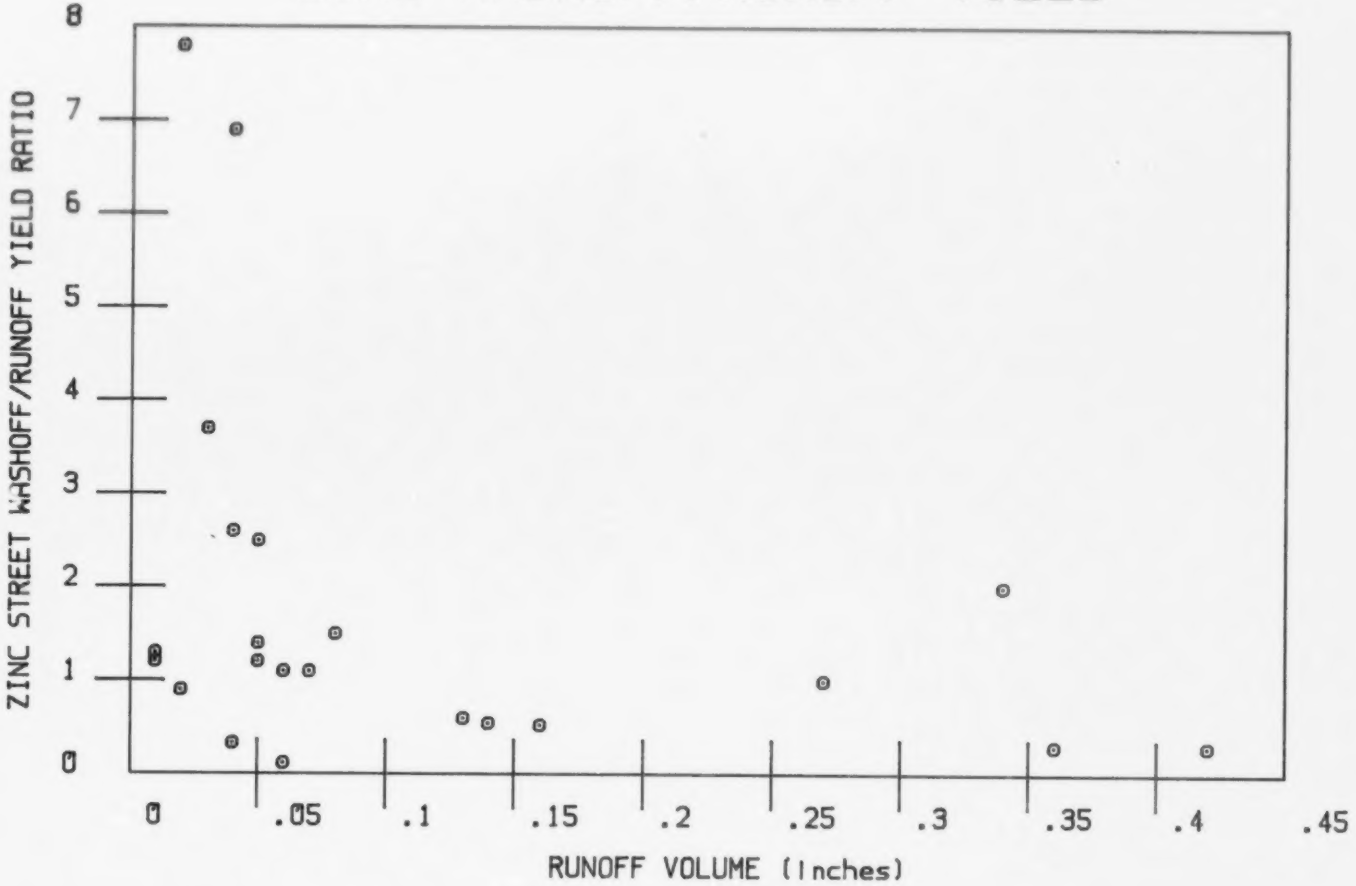

FIGURE B-40

TOTAL SOLIDS YIELDS: DRY SEASON

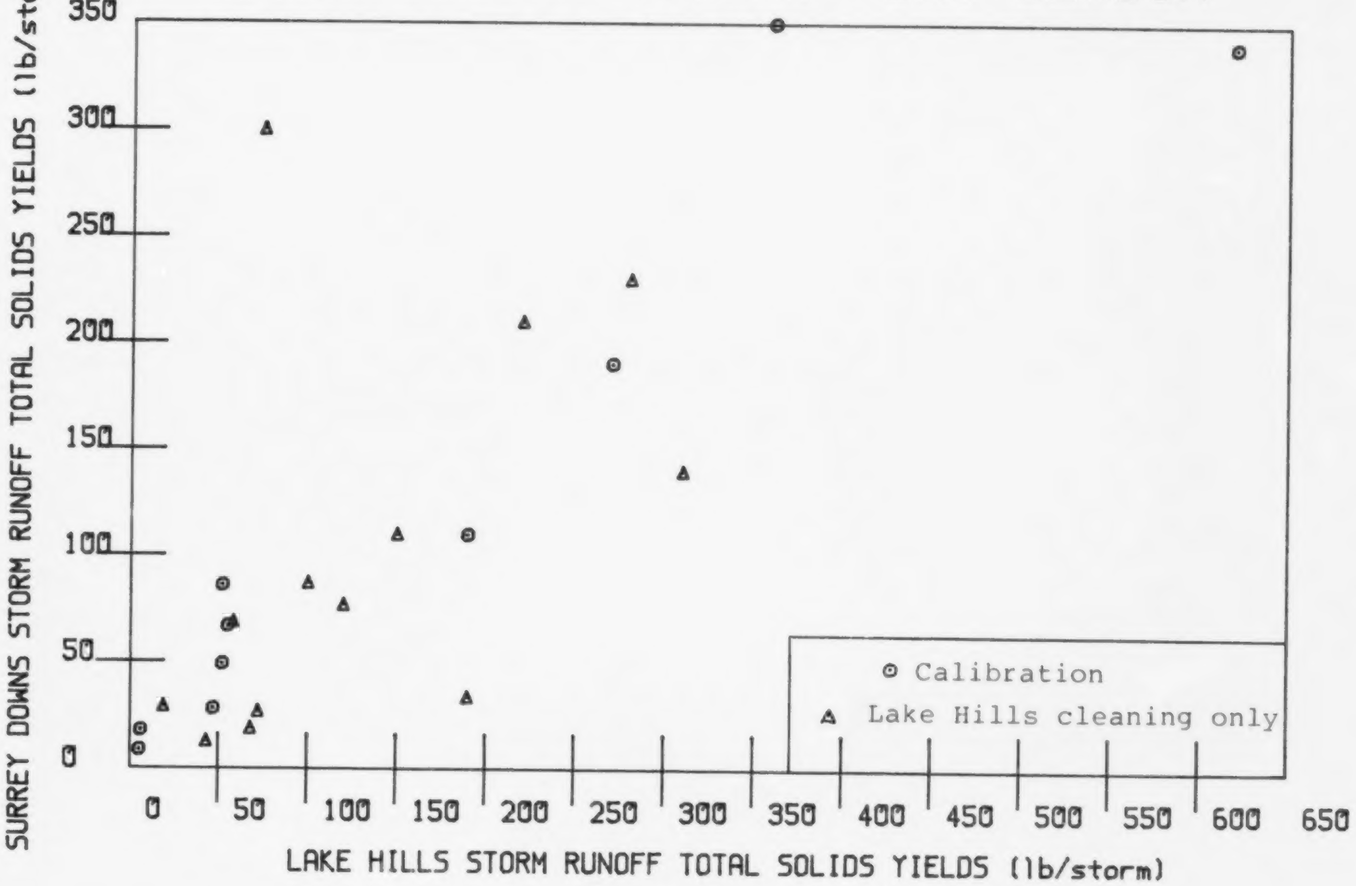

FIGURE B-41

TOTAL SOLIDS YIELDS: WET SEASON

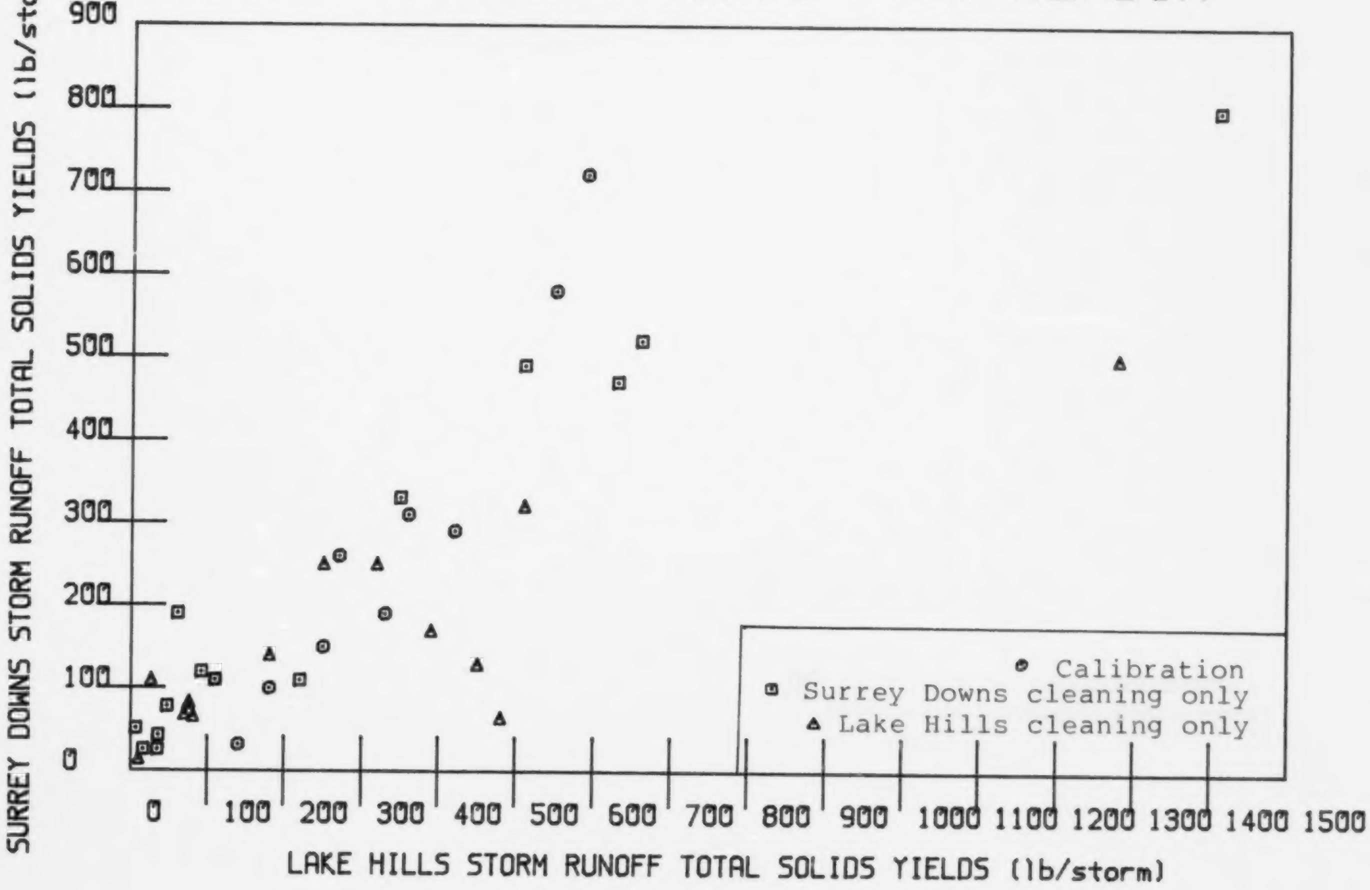

FIGURE B-42

TOTAL SOLIDS CONC.: DRY SEASON

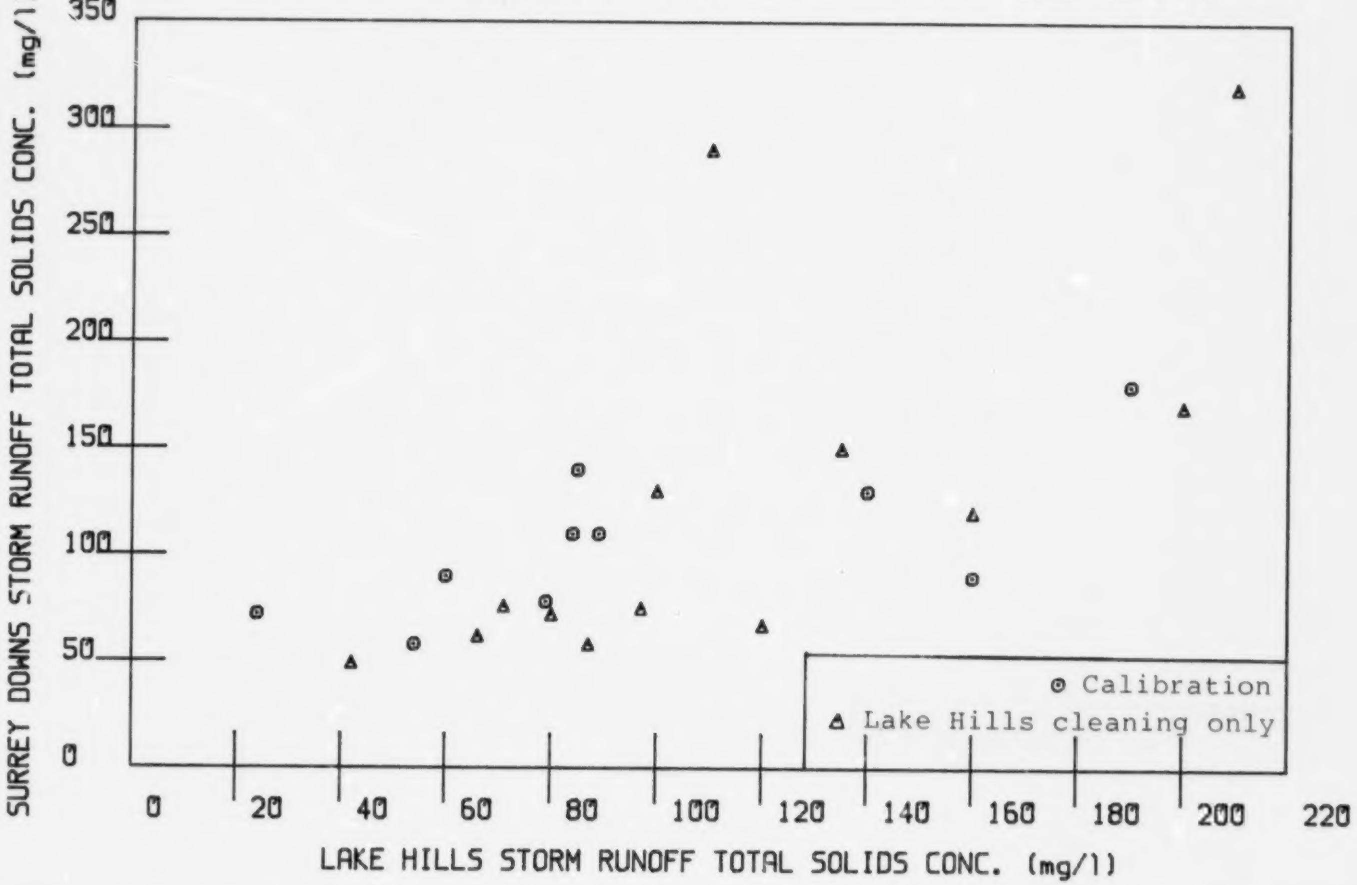

FIGURE B-43

TOTAL SOLIDS CONC.: WET SEASON

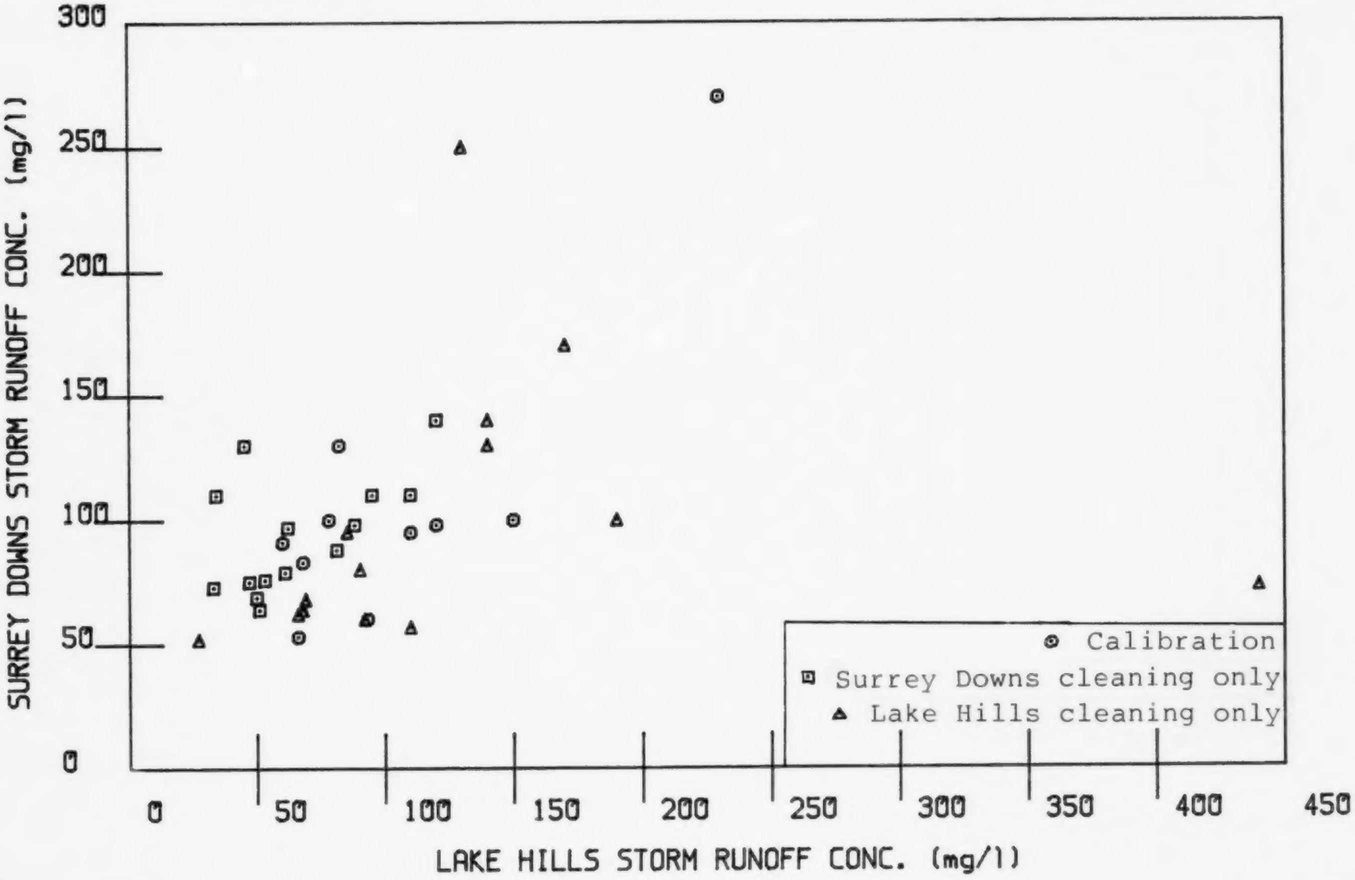

Table C-1.
Street Cleaning Effects on Street Loads for Other Bellevue Sites (lb/curb-mile)

Site and Date	before or after cleaning	Particle Size (Microns) <63	63-125	125-250	250-500	500-1000	1000-2000	2000-6350	>6350	total solids	total solids percent removal
2nd Ave.											
4/30/81	before	78.2	50.5	87.6	137	135	77.4	76.7	46.7	689	
	after	61.1	42.2	70.3	106	97.1	40.5	20.4	14.2	452	34%
5/22	before	222	149	305	483	378	242	446	430	2650	
	after	114	142	128	148	115	51.2	34.9	5.7	739	72
120th											
4/30	before	28.2	48.3	96.6	202	219	106	65.6	27.2	793	
	after	30.1	53.0	101	182	145	38.4	14.4	1.7	565	29
5/22	before	23.9	36.4	74.6	143	154	54.5	20.1	3.3	509	
	after	37.4	43.5	76.0	108	83.8	32.7	9.5	1.0	392	23
Kelsey Cr. Pky.											
4/30	before	16.3	21.0	43.8	69.1	75.0	67.2	57.3	21.5	371	
	after	36.4	28.0	43.9	51.5	35.8	14.4	13.7	24.3	248	33
5/22	before	42.6	31.0	47.5	48.0	39.3	20.9	17.1	5.2	252	
	after	22.0	17.2	26.7	33.8	28.0	9.5	5.3	1.6	144	43
118th											
4/30	before	11.8	7.2	8.4	15.5	39.3	54.0	53.6	9.3	200	
	after	43.0	23.0	28.7	35.1	44.4	38.3	24.9	2.7	240	-20
5/22	before	5.2	3.9	5.5	11.1	29.0	38.6	39.0	10.5	143	
	after	21.7	14.8	16.9	22.4	33.2	24.4	14.6	4.7	153	-7
Stoneridge											
5/5	before	25.6	31.2	47.5	66.6	64.1	34.5	24.5	14.6	309	
	after	38.1	29.6	47.1	59.0	50.2	21.5	9.2	5.4	260	16
SE 30th St.											
5/5	before	351	439	773	1050	826	420	242	82.9	4180	
	after	249	203	188	174	196	160	62.3	52.1	1280	69
Bellevue Way											
5/5	before	31.0	50.5	81.0	110	130	106	112	22.2	643	
	after	30.8	40.5	61.1	78.6	85.2	62.1	52.3	3.6	414	36
Bellevue North											
5/6	before	39.2	25.1	33.4	39.3	34.6	12.1	8.6	2.9	195	--

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Table C-2
Redistribution of Street Dirt due to Street Cleaning (10^{-3} lb/ft^2 loadings)

Site: 115-110th Ave. SE (SD2)
4/14/82 tests

	Particle Size (Microns)								
	>6350	2000-6350	1000-2000	500-1000	250-500	125-250	63-125	<63	total solids
Before									
0-10"	0.29	0.48	0.39	0.58	1.2	1.1	0.50	0.18	4.7
10"-20"	0.8	4.5	2.1	2.3	2.3	1.6	0.8	0.4	14.8
20"-4'	0.06	1.0	0.58	0.80	0.59	0.26	0.14	0.10	3.6
4'-8'	0.006	0.18	0.17	0.26	0.15	0.04	0.03	0.03	0.9
8'-15'	0.003	0.05	0.08	0.16	0.10	0.03	0.02	0.02	0.4
0-15'									2.1 (165 lb/ curb mile)
After									
0-10"	0.03	0.03	0.08	0.18	0.48	0.71	0.45	0.26	2.2
10"-20"	2.3	5.8	3.3	6.5	8.2	5.5	2.7	1.3	35.7
20"-4'	0.01	1.0	0.84	1.3	1.2	0.63	0.28	0.21	5.5
4'-8'	0.006	0.08	0.14	0.34	0.28	0.11	0.06	0.06	1.1
8'-15'	0.02	0.13	0.10	0.18	0.12	0.04	0.02	0.03	0.6
0-15'									3.5 (280 lb/ curb mile)
Removed									
0-10"	0.26	0.45	0.31	0.40	0.72	0.39	0.05	-0.08	2.5
10"-20"	-1.50	-1.30	-1.20	-4.2	-5.9	-3.9	-1.9	-0.9	-20.9
20"-4'	0.05	0.00	-0.26	-0.5	-0.6	-0.37	-0.14	-0.11	-1.9
4'-8'	0.00	0.10	0.03	-0.08	-0.13	-0.07	-0.03	-0.03	-0.2
8'-15'	-0.02	-0.08	-0.02	-0.02	-0.02	-0.01	0.00	-0.01	-0.2
									1.5
% Removed									
0-10"	90%	94%	79%	69%	60%	35%	10%	-44%	54%
10"-20"	-190	-29	-57	-180	-260	-240	-240	-225	-140
20"-4'	83	0.00	-45	-62	-100	-140	-100	-110	-53
4'-8'	0.00	0.56	18	-31	-87	-180	-100	-100	-21
8'-15'	-600	-160	-25	-13	-20	-33	0.00	-50	-47
0-15'									-70

Notes: (lawn mowed between before & after sunny/dry, good street condition)

Table C-2 (con't.)
Redistribution of Street Dirt due to Street Cleaning (10^{-3} lb/ft^2 loadings)

Site: 405-110th Ave. SE (SD1)
4/14/82 tests

	Particle Size (Microns)								
	> 6350	2000-6350	1000-2000	500-1000	250-500	125-250	63-125	<63	total solids
Before									
0-10"	1.03	1.6	1.7	4.3	4.7	3.1	1.3	0.58	18.4
10"-20"	0.29	1.8	0.55	1.1	1.8	1.6	0.77	0.34	8.2
20"-4'	0.67	2.2	0.86	0.96	0.81	0.58	0.37	0.37	6.8
4'-8'	0.006	0.29	0.44	0.52	0.36	0.17	0.10	0.12	2.0
8'-15'	0.003	0.08	0.09	0.10	0.04	0.01	0.01	0.01	0.3
0-15'									3.2 (256 lb/ curb mile)
After									
0-10"	0.32	1.27	0.10	0.79	0.92	0.13	0.24	0.08	4.8
10"-20"	1.11	0.84	0.84	1.7	2.0	1.5	0.74	0.45	9.2
20"-4'	0.14	0.42	0.63	1.2	1.6	1.0	0.50	0.32	5.8
4'-8'	0.006	0.33	0.39	0.59	0.42	0.20	0.10	0.10	2.1
8'-15'	0.02	0.22	0.14	0.17	0.07	0.03	0.02	0.03	0.7
0-15'									2.6 (204 lb/ curb mile)
Removed									
0-10"	0.71	0.33	1.6	3.5	3.8	3.0	1.1	0.50	13.6
10"-20"	-0.82	0.96	-0.29	-0.6	-0.2	0.1	0.03	-0.11	-1.0
20"-4'	0.53	1.8	0.23	-0.2	-0.8	-0.4	-0.13	0.05	1.0
4'-8'	?	-0.04	0.05	-0.07	-0.06	-0.03	0.00	0.02	-0.1
8'-15'	-0.02	-0.14	-0.05	-0.07	-0.03	-0.02	-0.01	-0.02	-0.4
									0.6
% Removed									
0-10"	69%	21%	94%	82%	80%	96%	82%	86%	74%
10"-20"	-280	53	-52	-55	-11	6	4	-32	-12
20"-4'	79	81	27	-25	-97	-72	-35	14	15
4'-8'	?	-14	11	-13	-17	-18	0.00	17	-7
8'-15'	-600	-175	-56	-70	-75	-200	-100	-200	-110
0-15'									20

Notes: (adjacent driveway washed onto site between before and after sunny/dry, good street condition)

Table C-3.
Street Cleaning Test Results During Special Tymco Test Period

Initial Load (lb/curb-mile)

Surrey Downs	Date	>6350	2000 -6350	1000 -2000	500 -1000	250 -500	125 -250	63 -125	37 -63	<37	TS
Mobil	9/8	8.0	11.7	37.6	99.1	114.4	87.8	54.4	26.1	6.9	456
	9/14	5.0	18.2	29.3	59.4	58.9	40.5	24.1	10.5	6.2	252
	9/17	1.4	6.3	11.6	19.0	14.4	10.2	7.8	4.7	5.2	81
	9/22	8.6	16.3	25.7	50.7	62.1	52.8	38.0	15.2	8.8	278
Tymco	9/10	2.5	7.8	14.4	34.5	32.3	14.8	5.8	2.3	1.6	116
	9/15	2.1	14.1	25.6	49.3	52.9	39.5	29.9	10.6	13.7	238
	9/21	6.9	17.1	30.1	66.5	67.2	44.0	26.9	10.1	8.4	277
	9/23	3.0	18.8	46.8	110.4	113.8	73.7	39.9	16.6	11.9	435
Modified Tymco	9/10	5.1	16.2	46.5	121.5	171.5	142.8	88.7	39.7	19.7	652
	9/14	6.0	15.8	37.0	60.7	54.2	32.3	18.0	8.3	6.9	239
	9/21	2.1	6.3	15.5	24.5	32.5	29.3	24.7	9.7	7.3	152
	9/23	3.5	6.7	9.0	16.0	21.7	19.8	15.8	8.3	6.8	108

Residual Load (lb/curb-mile)

Surrey Downs	Date										
Mobil	9/8	1.3	14.4	38.9	99.4	114	82.3	52.7	24.8	20.9	449
	9/14	3.9	12.2	23.7	55.4	60.4	42.5	25.2	11.2	9.0	243
	9/17	3.1	6.3	12.7	24.5	23.2	16.7	10.8	5.1	5.5	108
	9/22	2.1	9.7	22.1	42.7	48.5	39.9	30.1	14.3	10.5	220
Tymco	9/10	1.7	5.3	9.1	23.1	19.7	15.7	11.2	6.9	5.8	99
	9/15	0.7	8.0	9.7	19.7	25.8	24.8	19.1	10.3	10.3	129
	9/21	0.5	6.5	12.5	23.3	21.7	18.0	13.8	6.6	5.1	111
	9/23	2.2	8.1	24.0	52.6	48.0	37.7	26.9	13.8	9.3	223
Modified Tymco	9/10	7.7	10.1	24.6	54.5	61.1	48.5	38.2	20.4	18.2	283
	9/14	0.3	7.3	13.6	22.1	18.2	12.7	8.8	5.3	6.4	95
	9/21	0.6	3.1	9.9	14.2	17.5	18.3	15.6	8.0	7.7	95
	9/23	0.8	4.9	5.8	10.3	12.0	11.9	9.8	5.8	5.1	66

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Table C-3, (Cont.)
Street Cleaning Test Results During Special Tymco Test Period

Initial Load (lb/curb-mile)

Surrey Downs	Date	Particle Size (Microns) >6350	2000 -6350	1000 -2000	500 -1000	250 -500	125 -250	63 -125	37 -63	<37	TS
SE 30th											
Mobil	9/1	141	251	285	532	740	667	284	66.7	20.8	2986
	9/16	17.1	80.4	146	321	390	384	302	98.1	99.8	1839
	9/27	1.2	32.2	83.5	125	137	119	73.9	20.8	6.9	600
	9/30	9.2	33.9	68.0	138	174	185	141	55.1	19.3	822
	10/5	5.5	21.5	34.4	54.2	55.5	48.7	27.3	8.8	5.2	261
Tymco	9/2	37.6	84.0	152	259	403	400	245	80.6	37.8	1699
	9/16	47.3	135	141	222	314	358	200	76.3	85.0	1578
	9/27	18.2	72.7	120	226	288	245	151	47.8	14.5	912
	10/1	11.2	27.1	38.4	60.5	70.0	72.1	43.6	16.9	9.4	349
	10/4	3.1	28.3	51.0	70.2	83.0	81.4	48.9	13.6	5.1	385
Modified Tymco	9/16	17.1	48.9	127	201	222	192	134	44.8	24.0	1009
	9/29	6.8	37.6	64.9	117	131	102	47.5	11.7	4.7	523
	9/30	7.8	31.5	73.3	133	205	186	90.0	22.4	5.8	755
	10/4	15.5	33.4	62.4	125	125	94.8	63.5	18.9	8.0	547

Residual Load (lb/curb-mile)

	Date	>6350	2000 -6350	1000 -2000	500 -1000	250 -500	125 -250	63 -125	37 -63	<37	TS
SE 30th											
Mobil	9/1	85.9	231	239	413	635	824	488	137	23.1	3077
	9/16	22.3	45.3	97.5	208	237	218	169	60.2	67.0	1123
	9/27	14.3	128	75.0	146	228	221	125	46.3	24.4	909
	9/30	8.4	36.2	68.0	126	144	121	69.7	24.2	11.3	610
	10/5	5.3	23.1	39.7	62.5	65.3	54.5	32.4	13.0	8.1	304
Tymco	9/2	7.0	31.5	113	153	216	223	145	58.0	43.9	991
	9/16	11.7	38.2	64.1	87.9	93.9	105	93.2	41.5	34.1	570
	9/27	6.9	29.2	84.8	149	136	127	84.6	34.7	13.0	664
	10/1	2.0	12.4	28.9	42.1	37.5	35.9	27.7	11.0	7.1	205
	10/4	1.9	20.4	38.0	47.1	45.3	46.1	34.7	12.7	6.6	252
Modified Tymco	9/16	6.2	18.3	66.6	81.5	74.4	76.2	74.5	34.7	33.5	446
	9/29	1.4	13.9	33.0	43.7	39.6	30.9	16.7	5.1	2.7	187
	9/30	6.8	20.3	70.3	83.9	55.0	37.8	26.2	9.5	6.2	316
	10/4	1.4	18.4	42.1	70.5	59.5	48.6	35.0	11.8	7.6	295

FIGURE C-1

Street Cleaner Performance - >6370 Microns

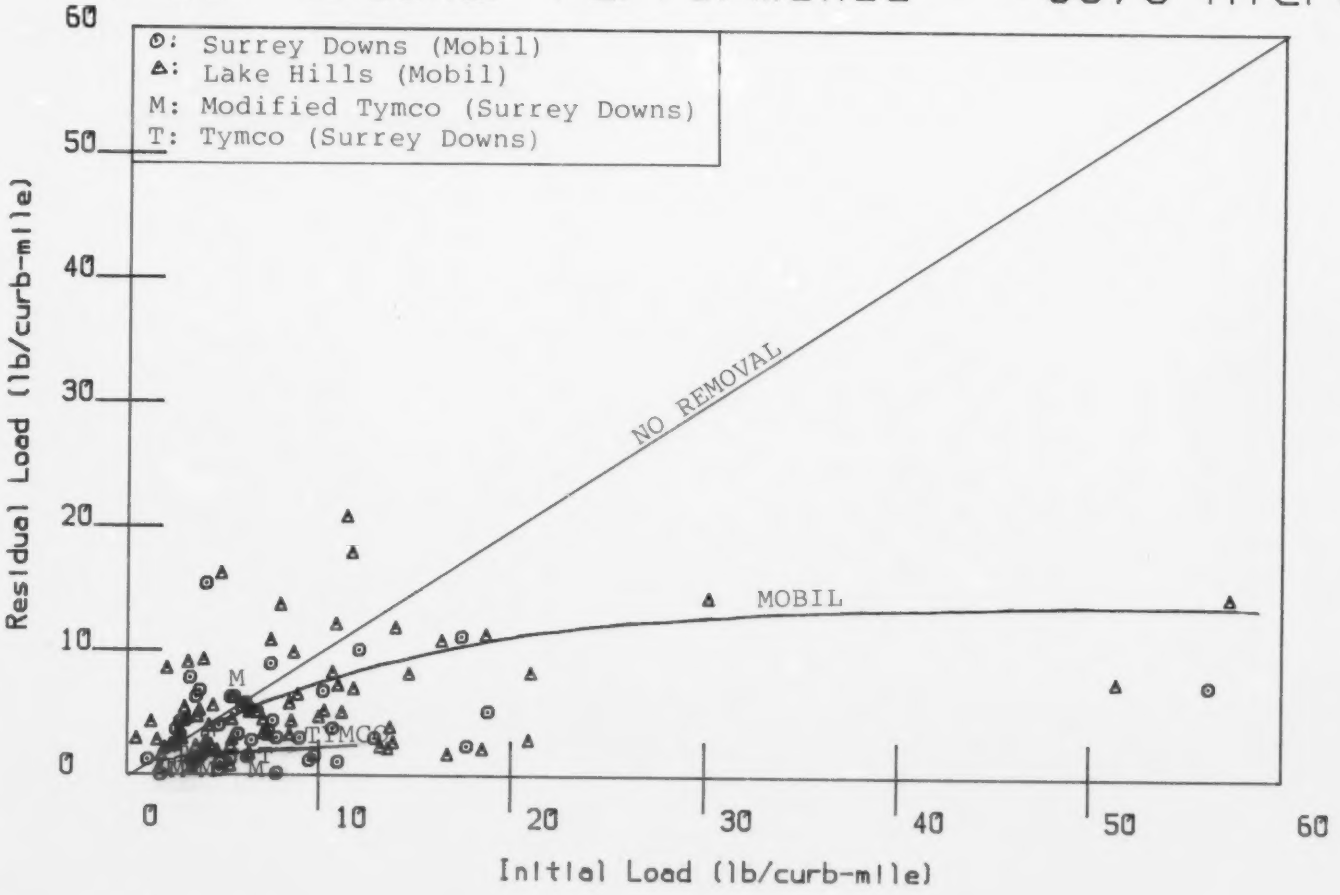


FIGURE C-2

Street Cleaner Performance: 2000-6370 μ

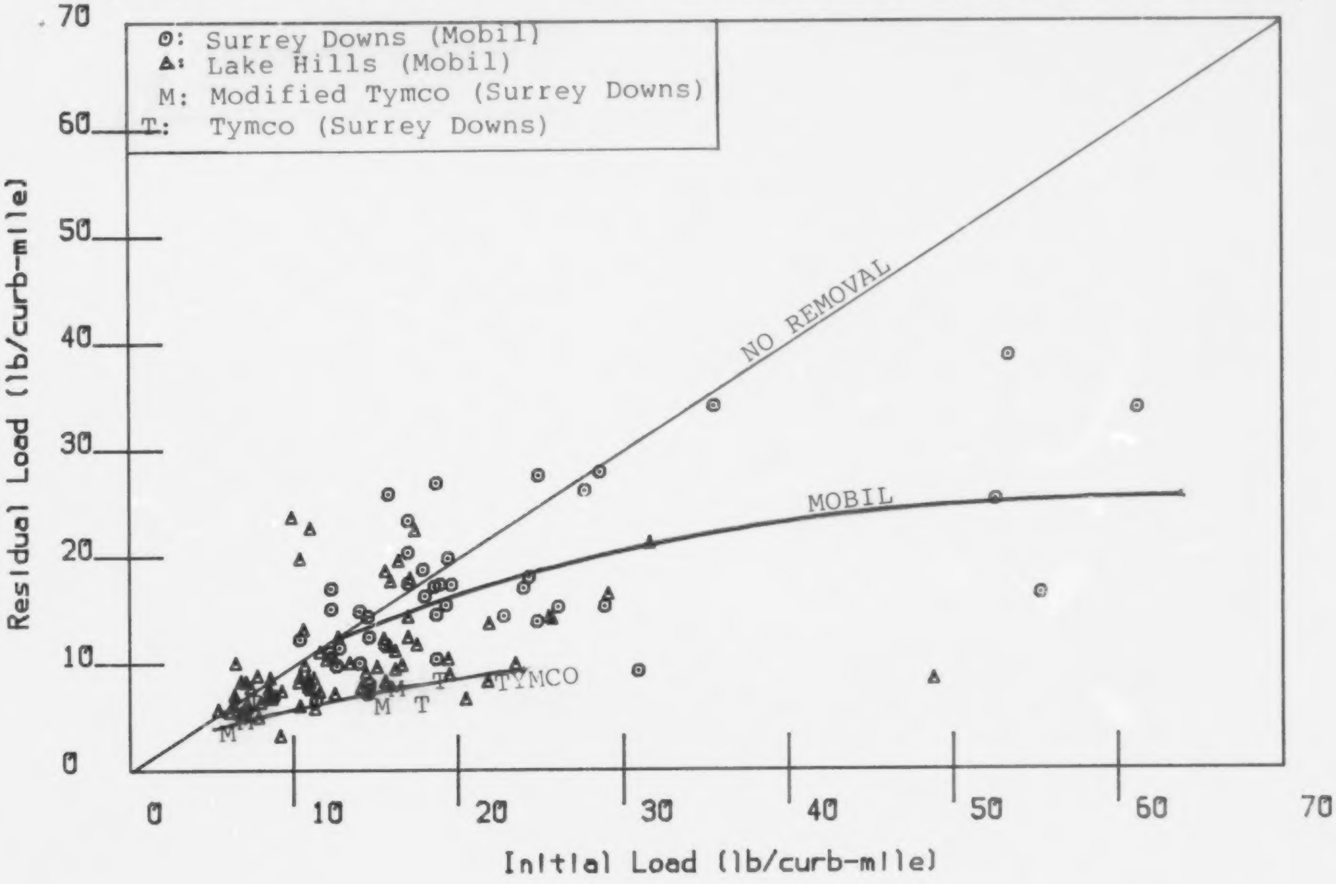


FIGURE C-3

Street Cleaner Performance: 1000-2000 μ

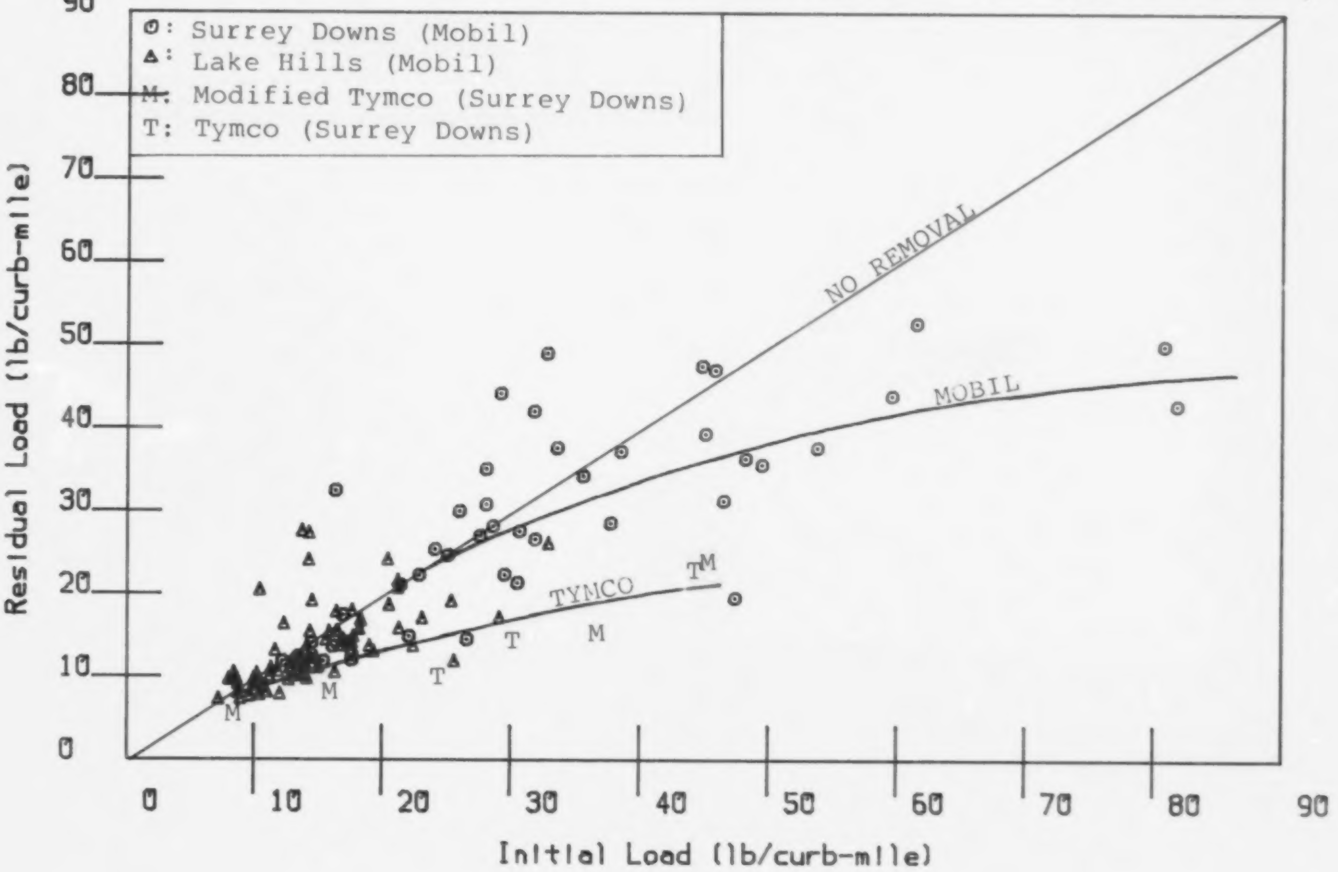


FIGURE C-4

Street Cleaner Performance: 500-1000 μ

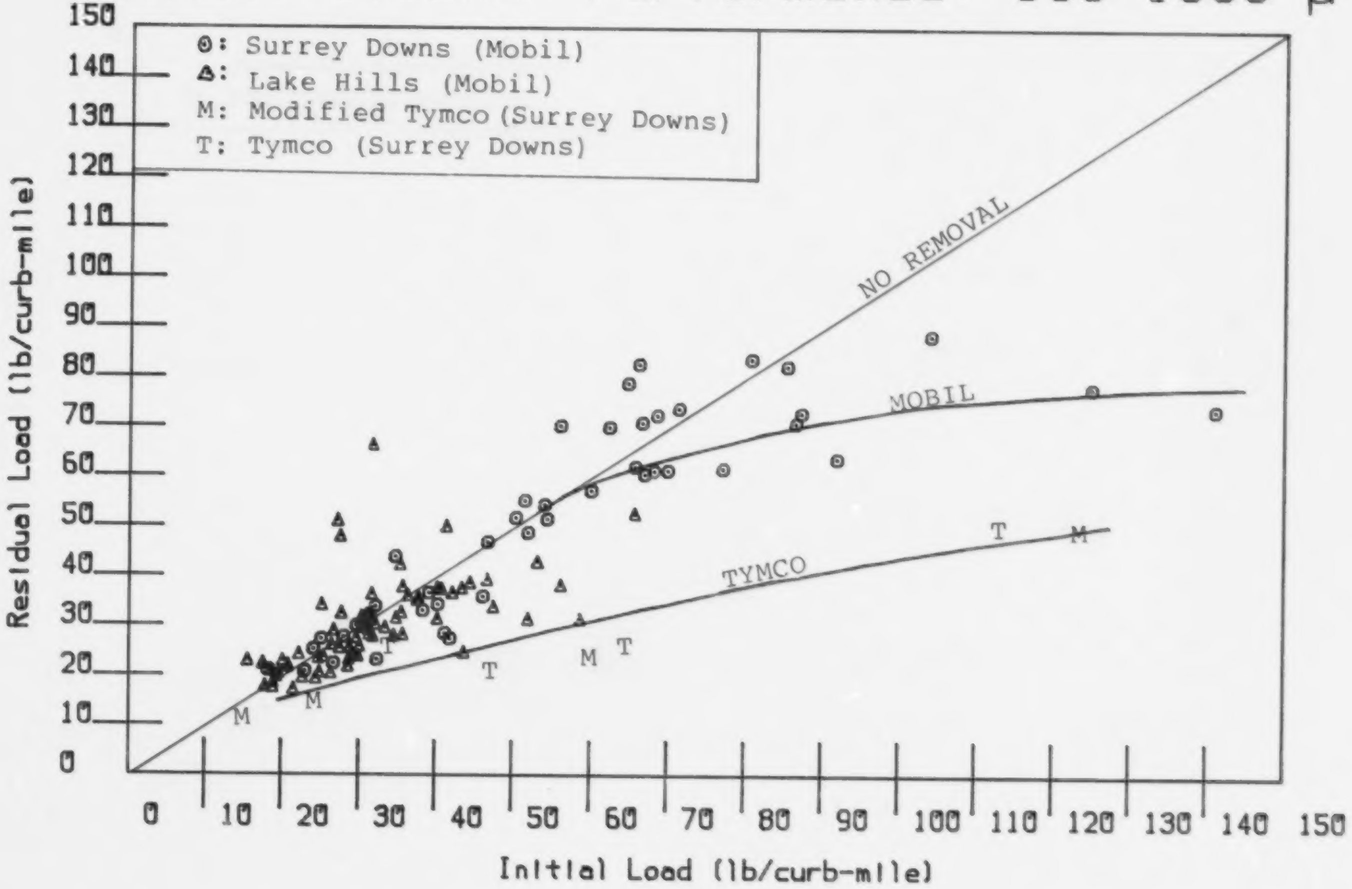


FIGURE C-5

Street Cleaner Performance: 250-500 μ

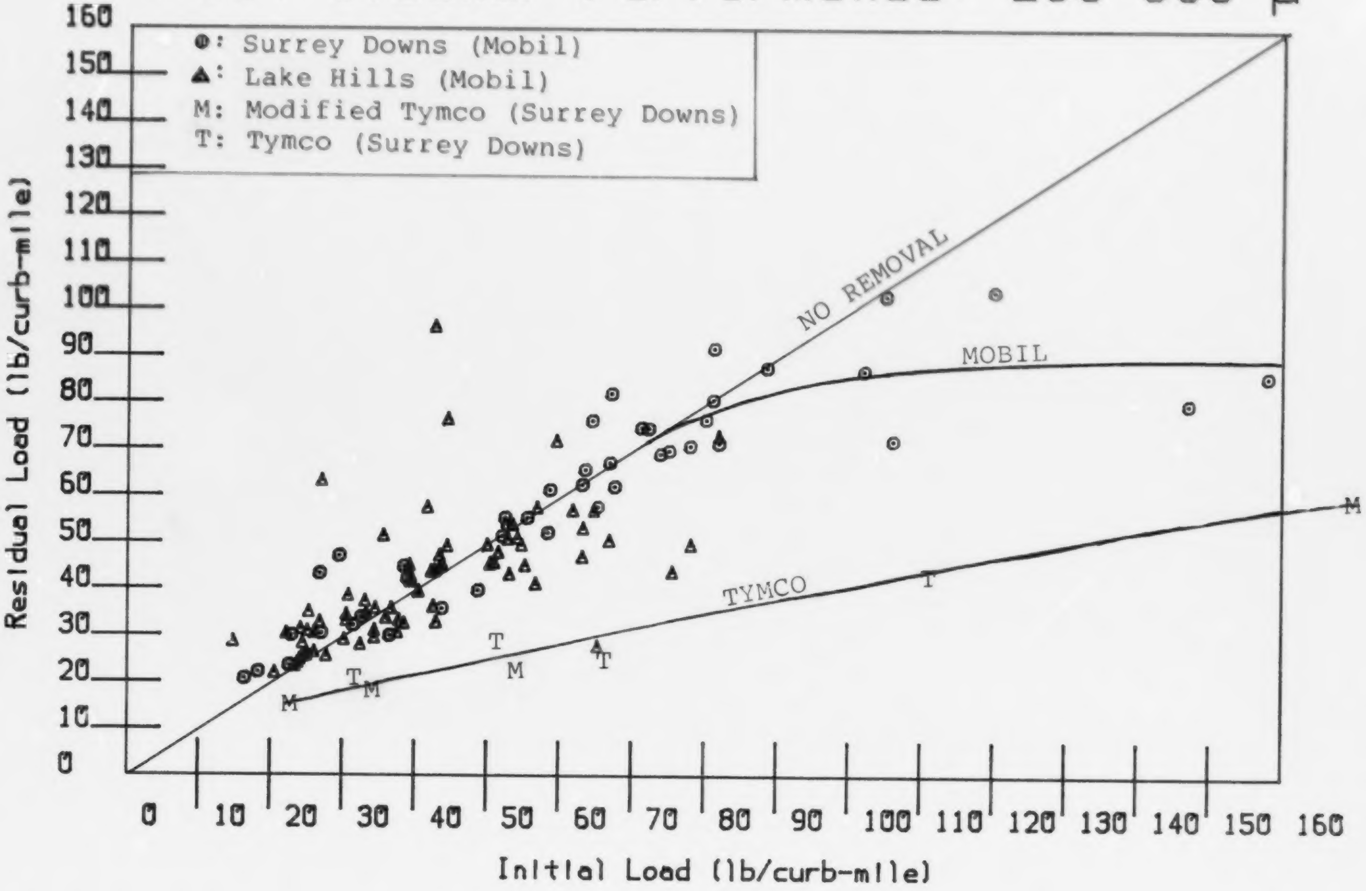


FIGURE C-6

Street Cleaner Performance: 125-250 μ

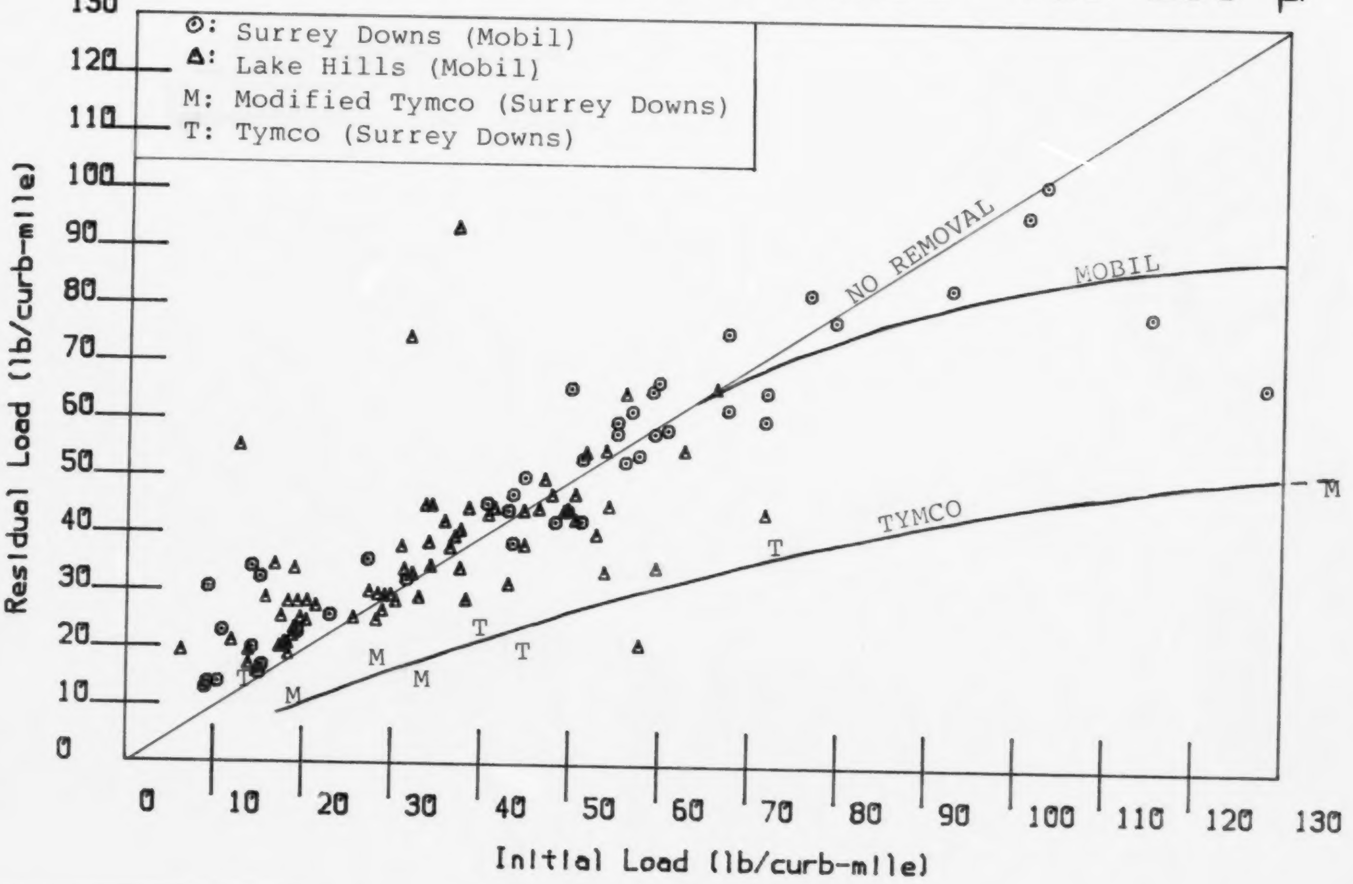
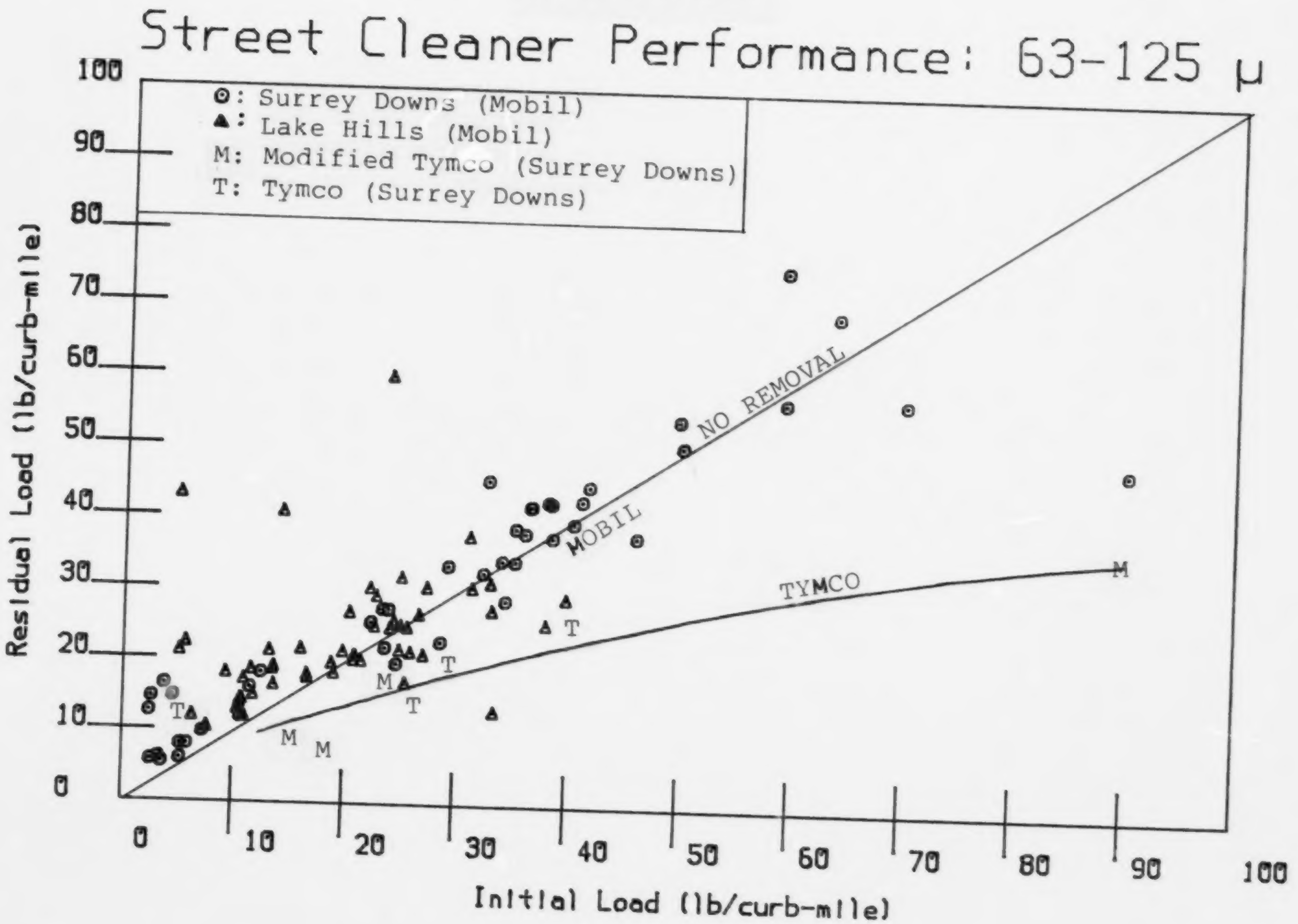


FIGURE C-7



Street Cleaner Performance: 63-125 μ

FIGURE C-8

Street Cleaner Performance: <63 Microns

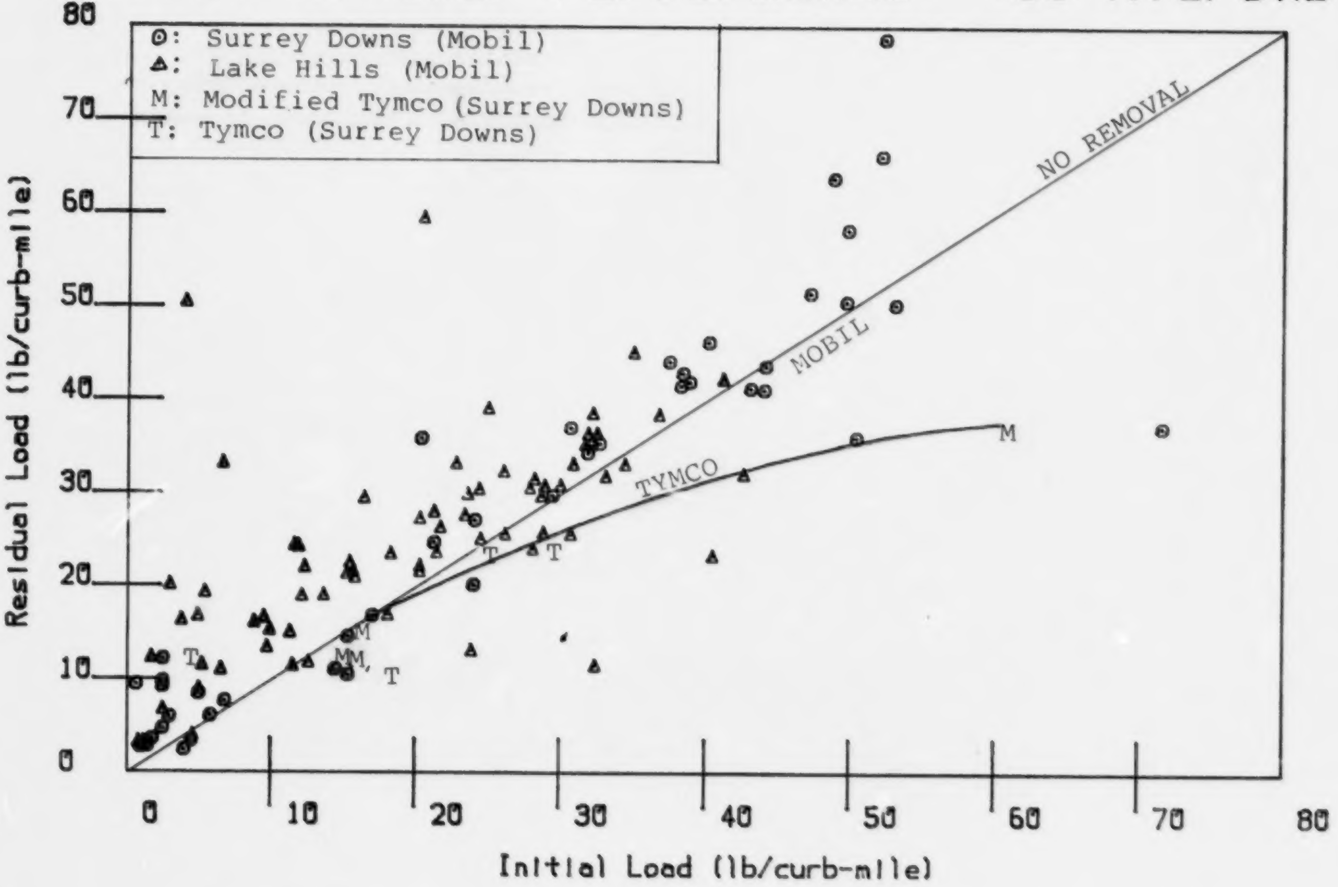


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FIGURE C-9

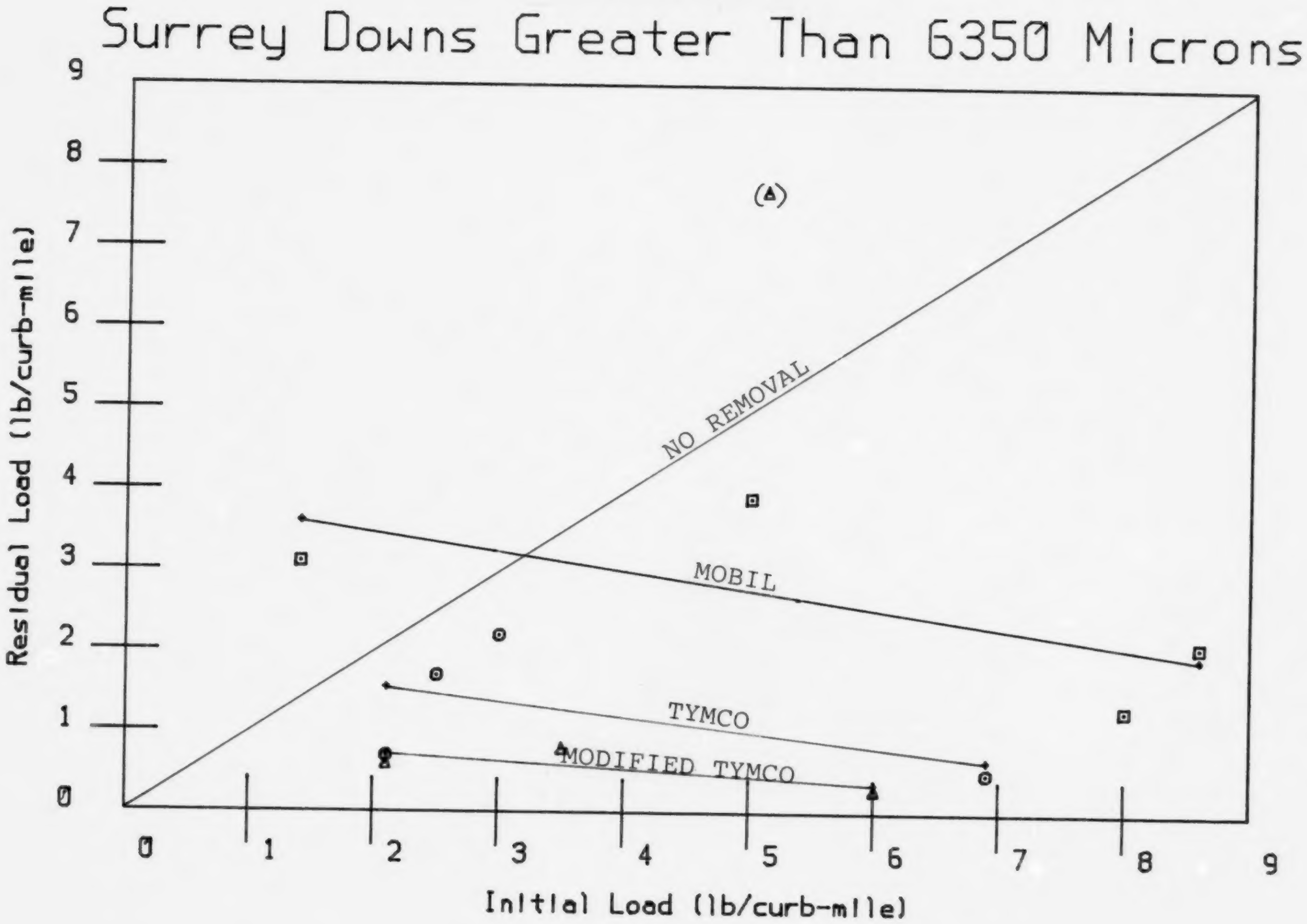
Surrey Downs Greater Than 6350 Microns

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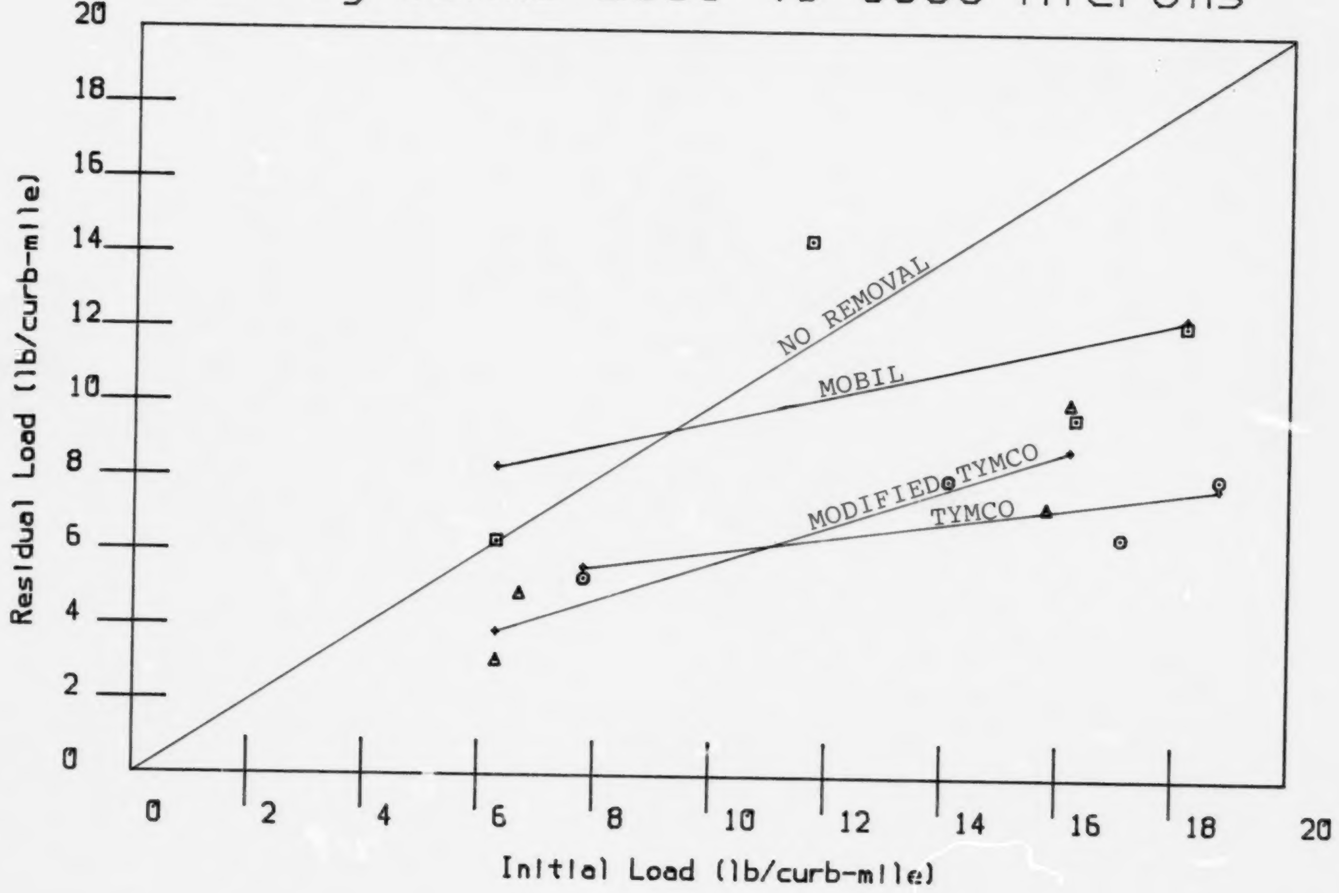
FIGURE C-10



Surrey Downs 2000 to 6350 Microns

FIGURE C-11

Surrey Downs 1000 to 2000 Microns

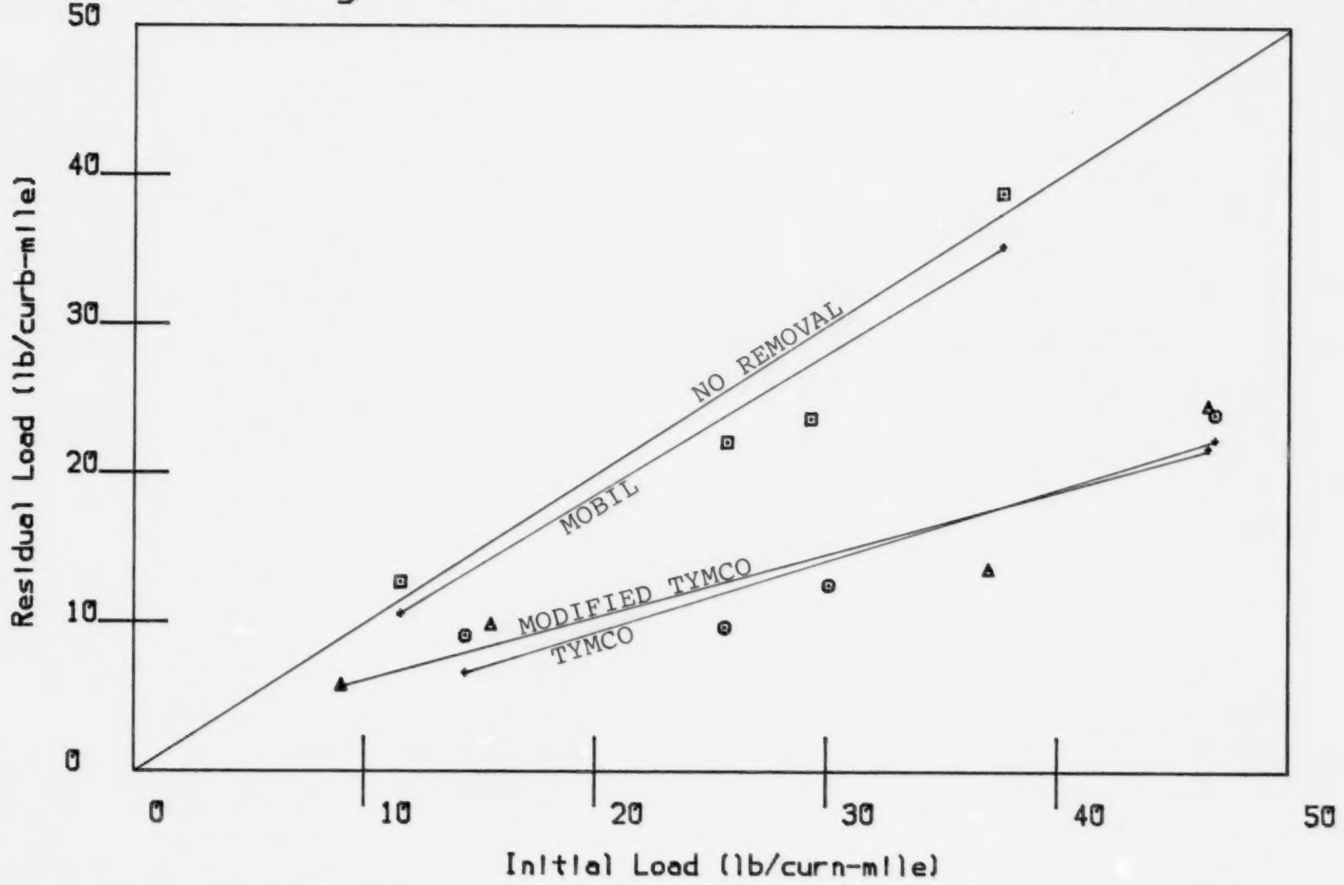


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FIGURE C-12

Surrey Downs 500 to 1000 Microns

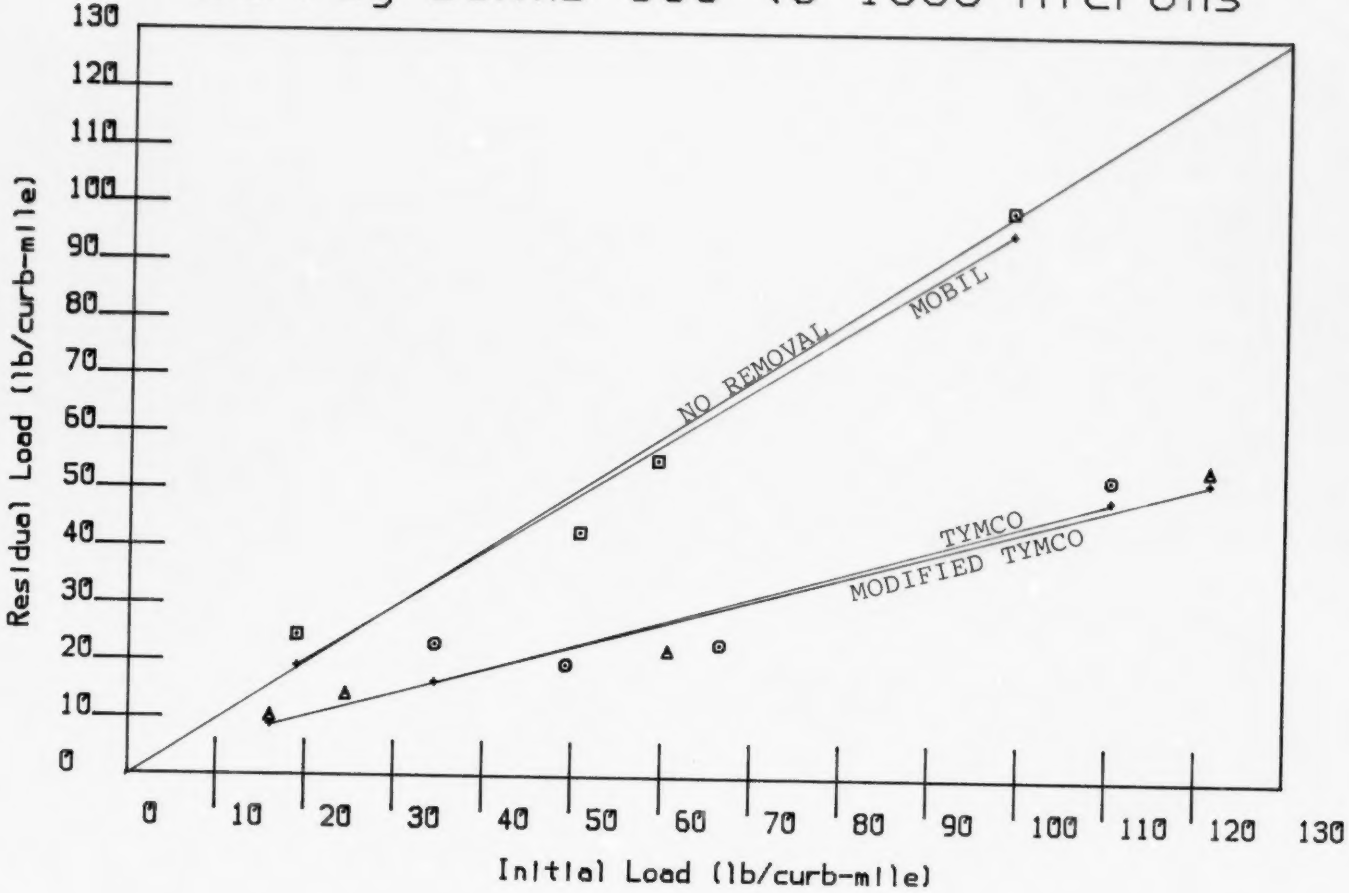

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FIGURE C-13

Surrey Downs 250 to 500 Microns

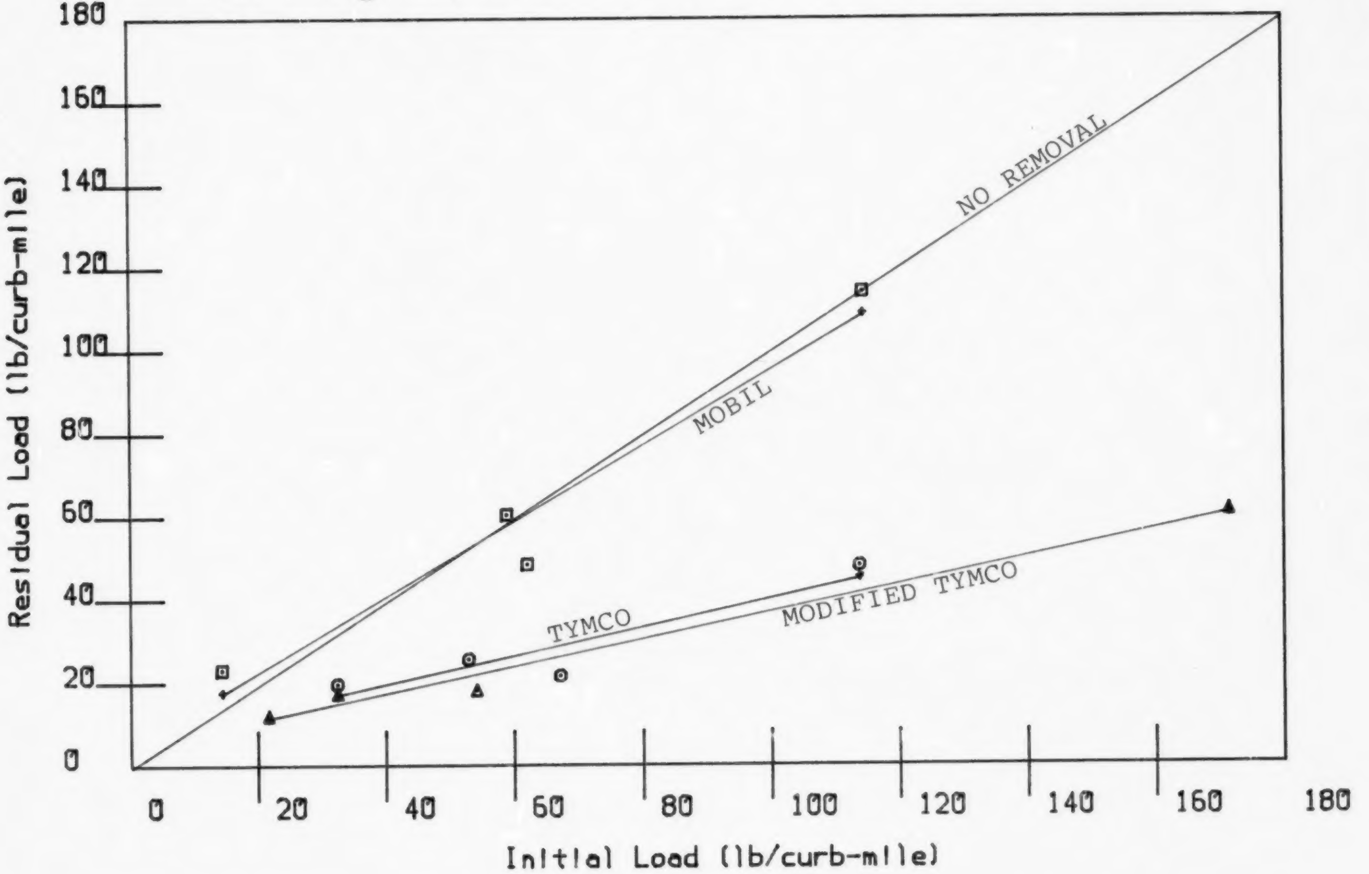

FIGURE C-14

Surrey Downs 125 to 250 Microns

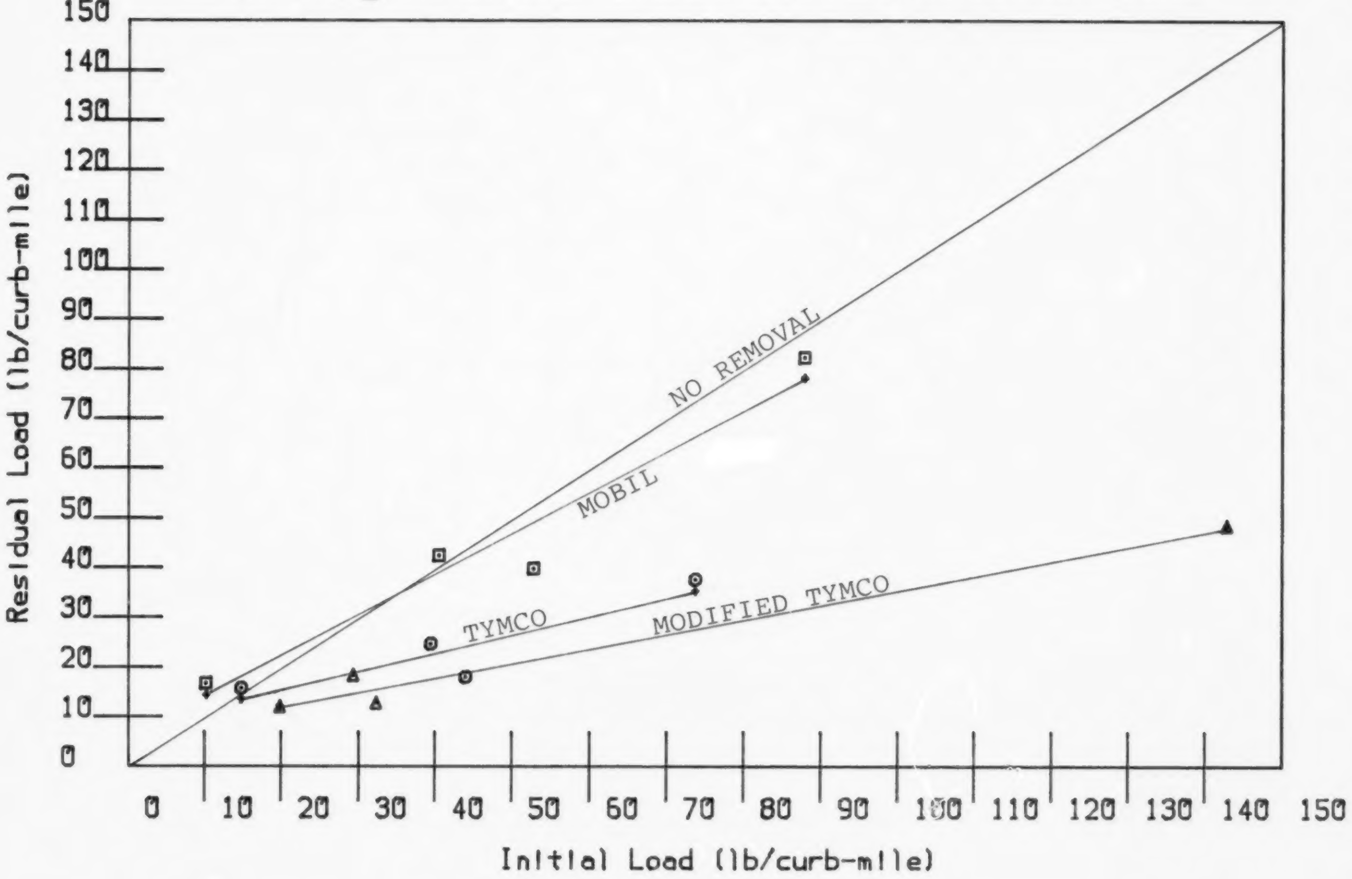

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FIGURE C-15

Surrey Downs 63 to 125 Microns

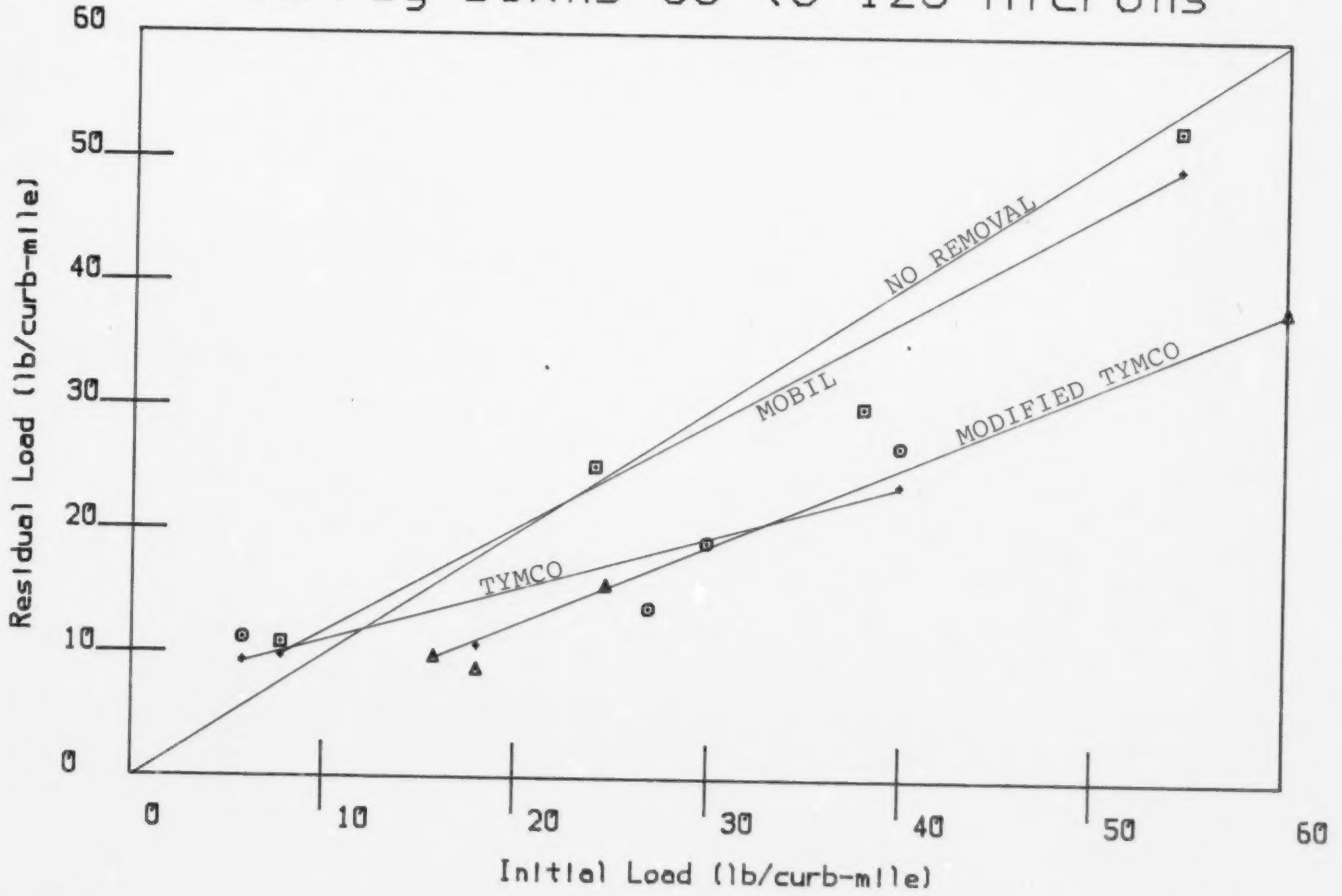

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FIGURE C-16

Surrey Downs 37 to 63 Microns

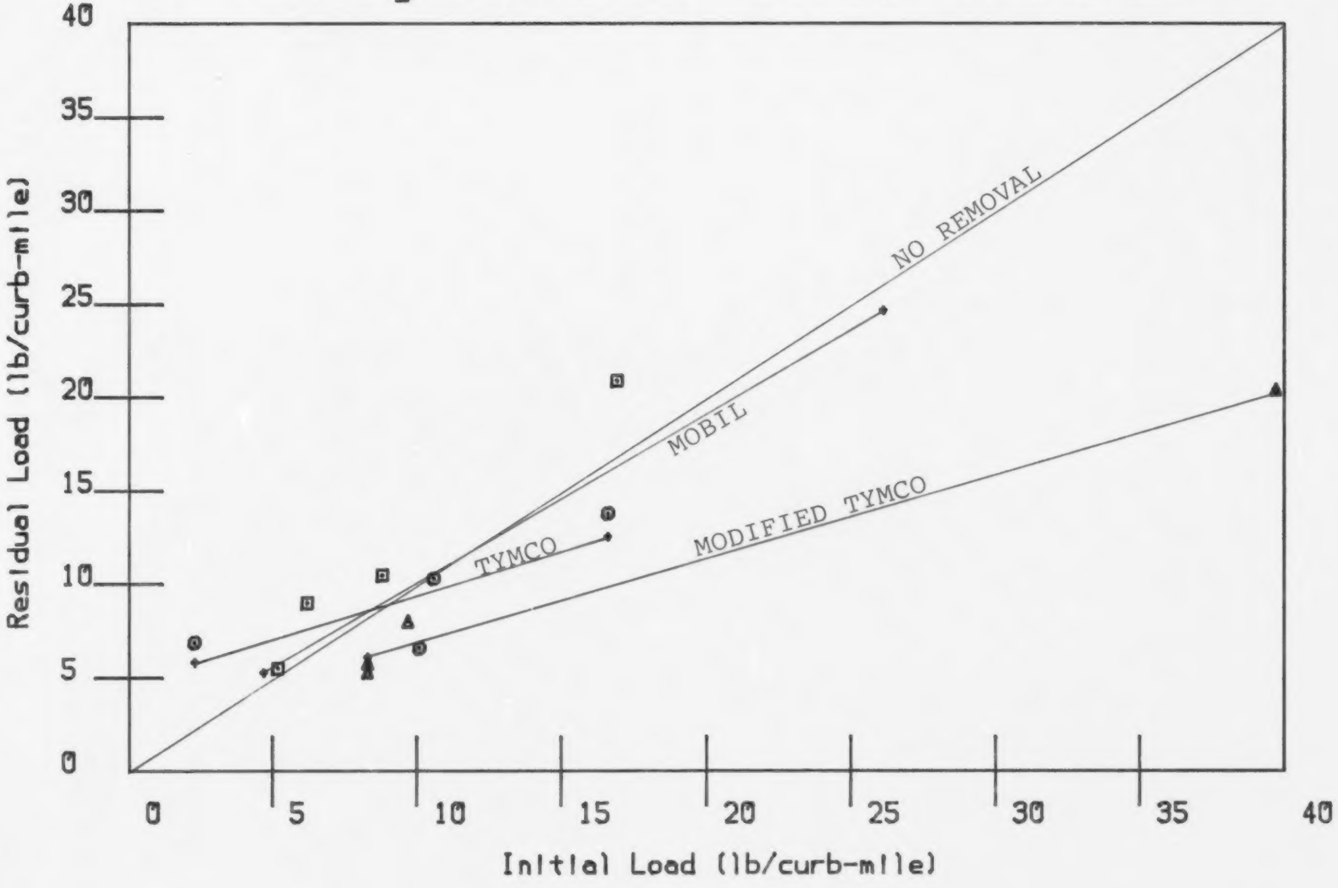

FIGURE C-17

Surrey Downs Less Than 37 Microns

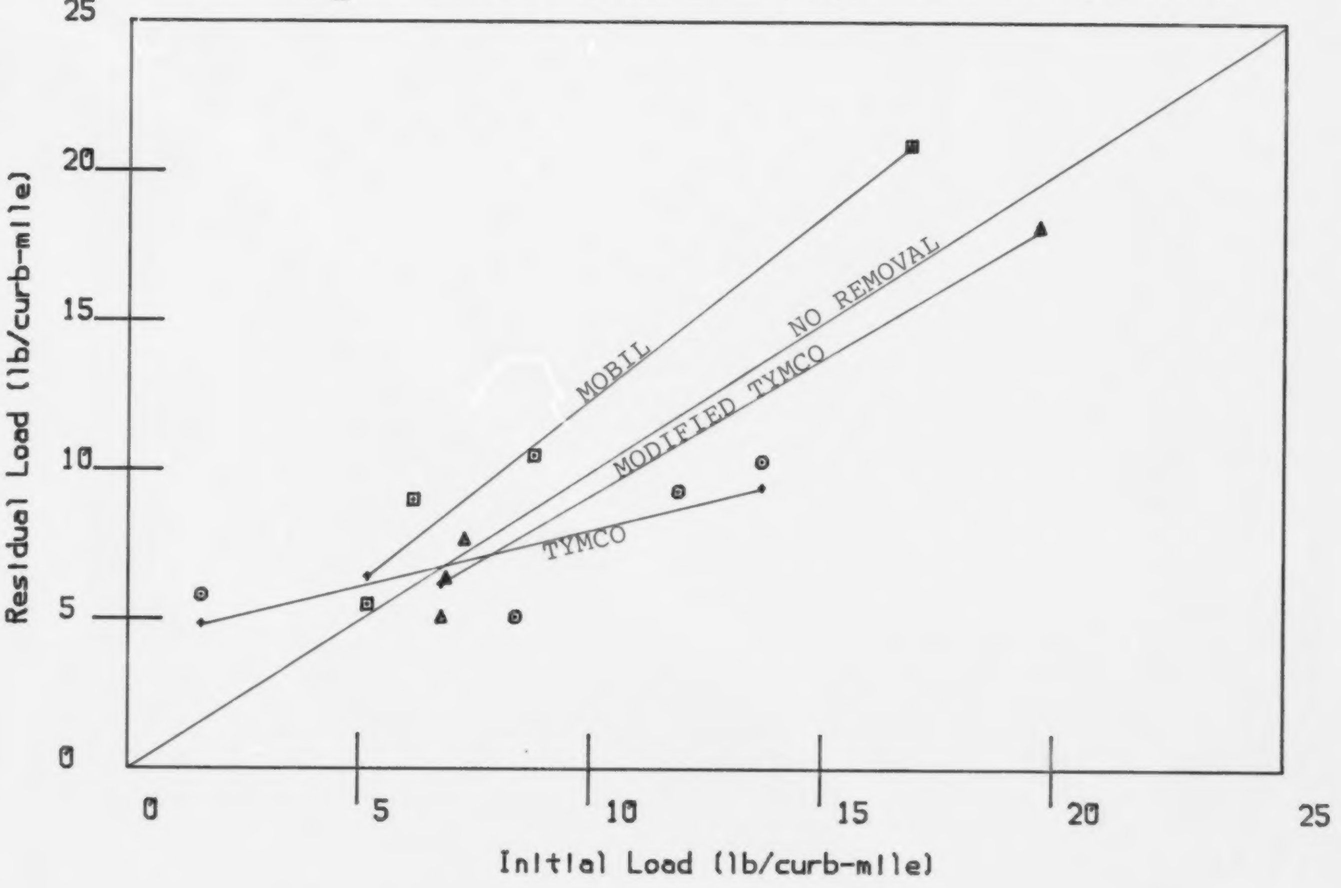

FIGURE C-18

Surrey Downs 2 to 10 Microns

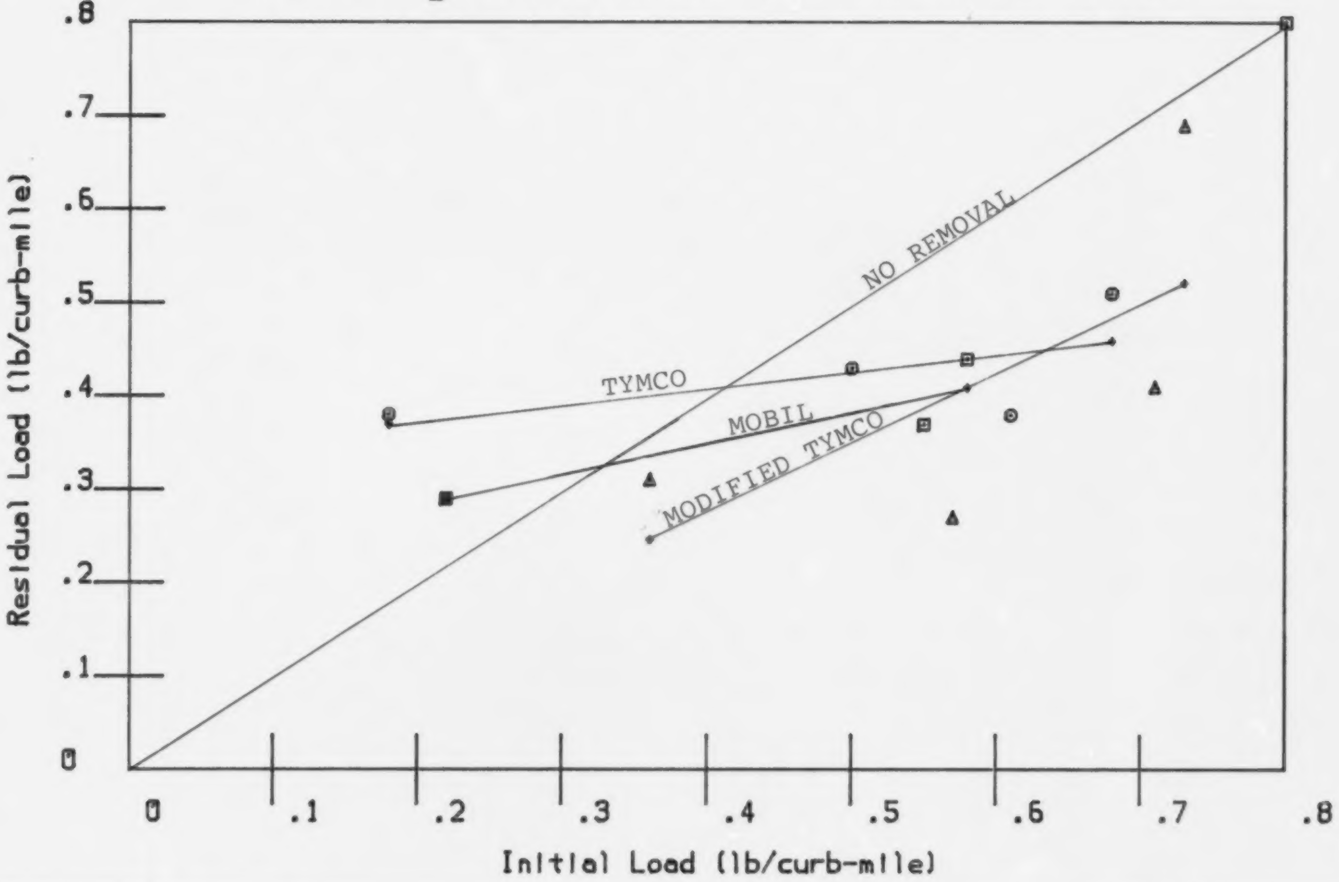

FIGURE C-19

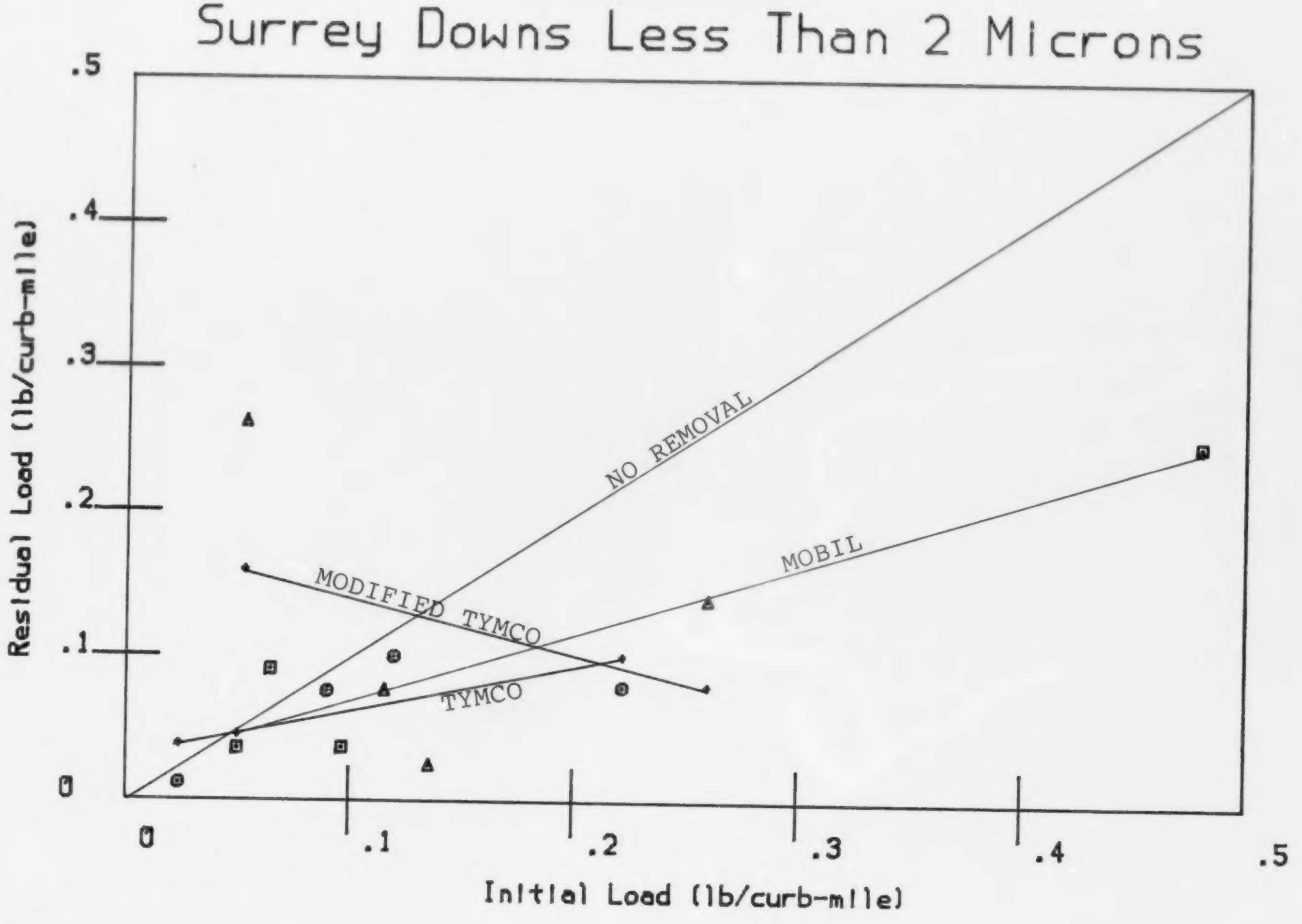
Surrey Downs Less Than 2 Microns
Residual Load (lb/curb-mile)
Initial Load (lb/curb-mile)
0
.1
.2
.3
.4
.5
NO REMOVAL
MOBIL
MODIFIED TYMCO
TYMCO

FIGURE C-20

S.E. 30th Greater Than 6350 Microns

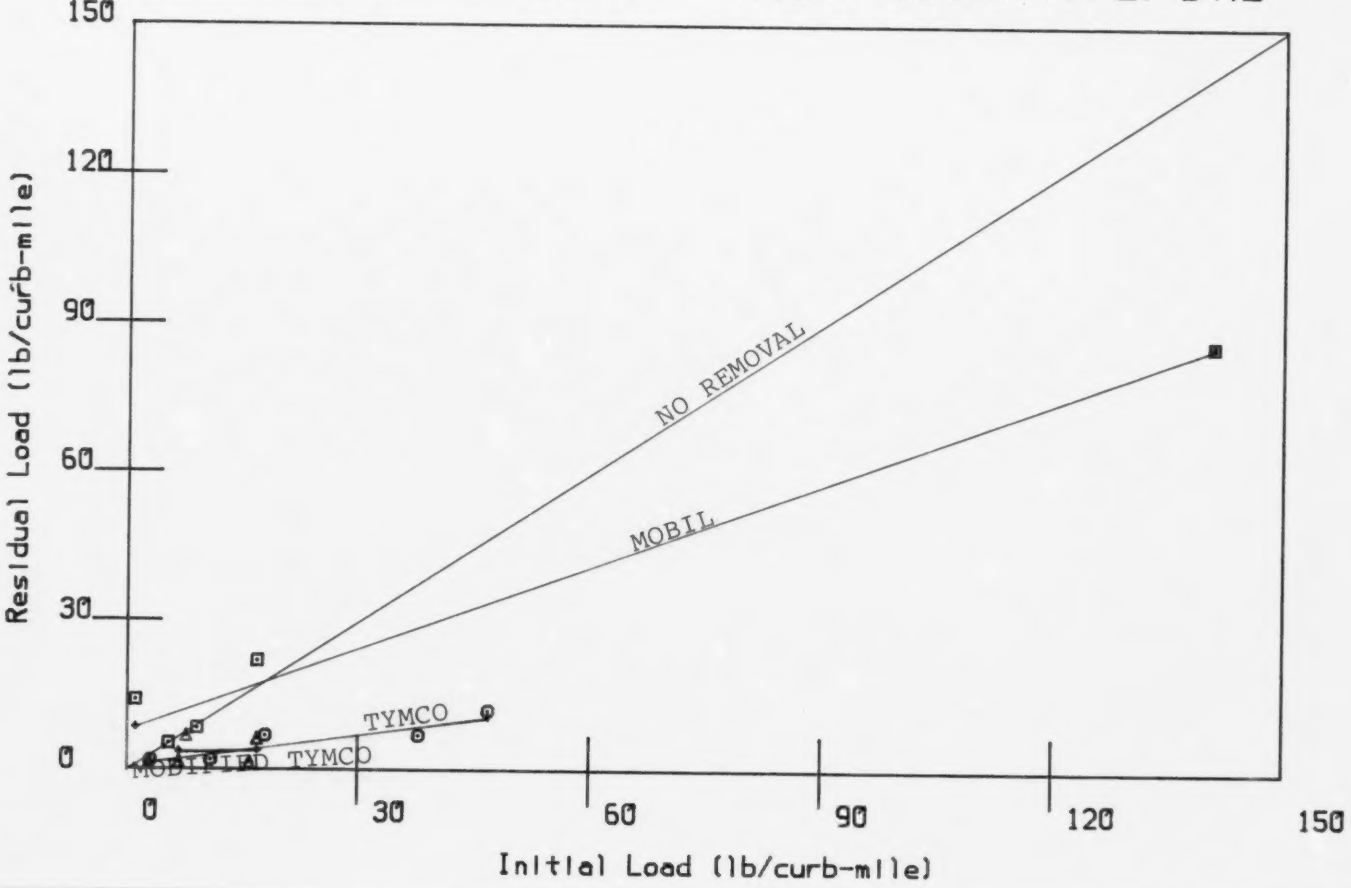

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FIGURE C-21

S.E. 30th 2000 to 6350 Microns

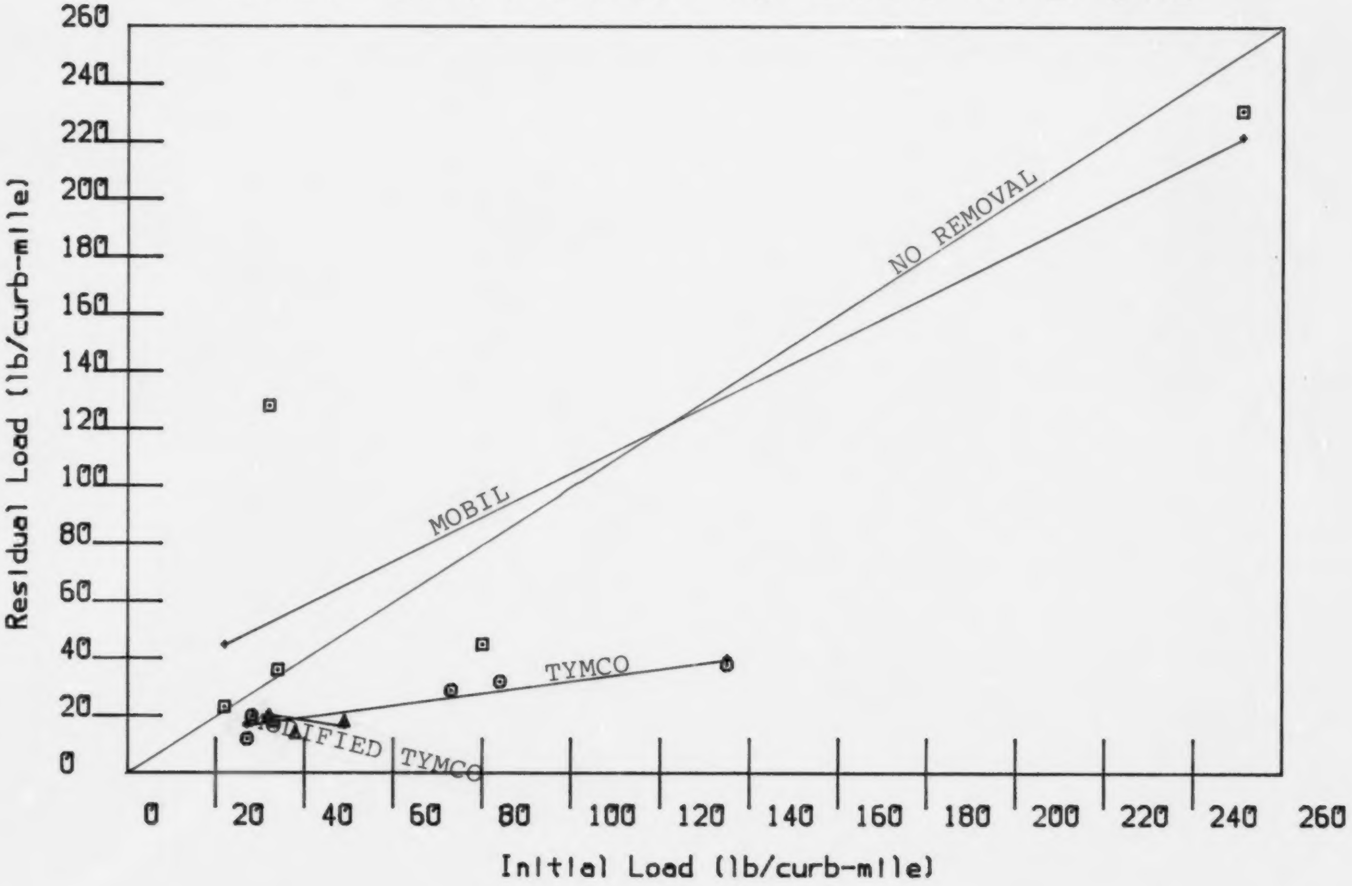

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FIGURE C-22

S.E. 30th 1000 to 2000 Microns

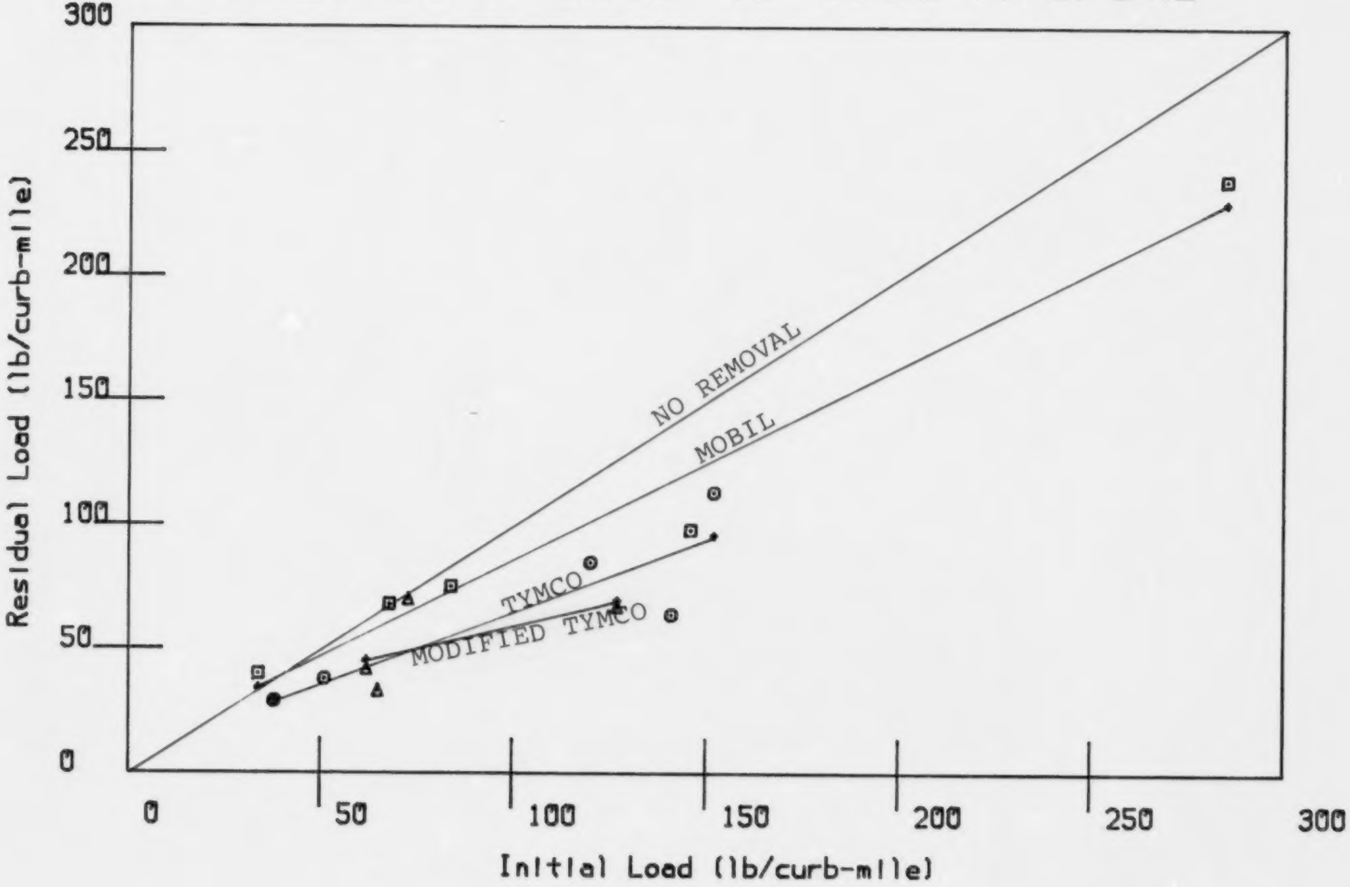
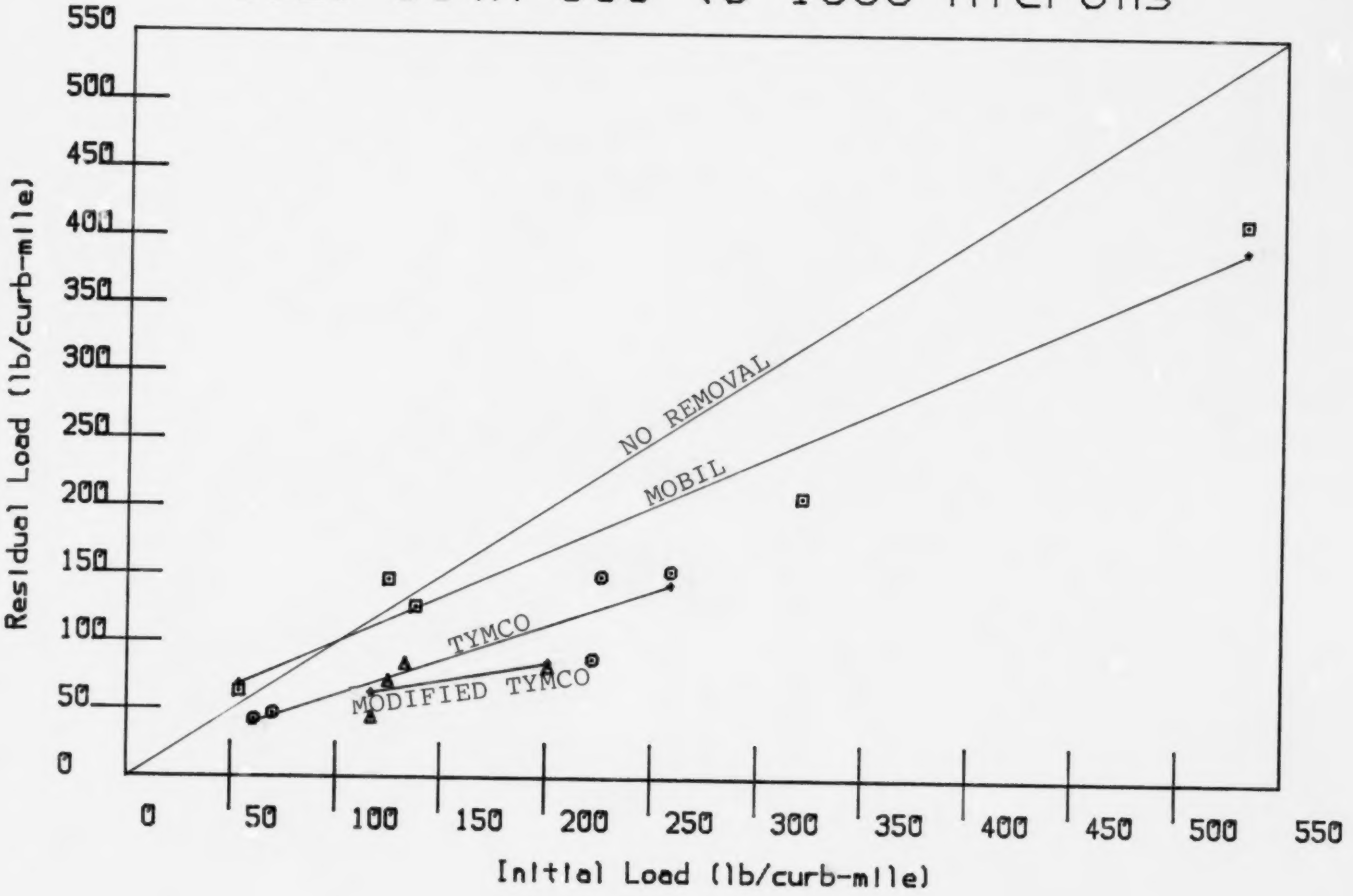


FIGURE C-23

S.E. 30th 500 to 1000 Microns



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BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA. OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
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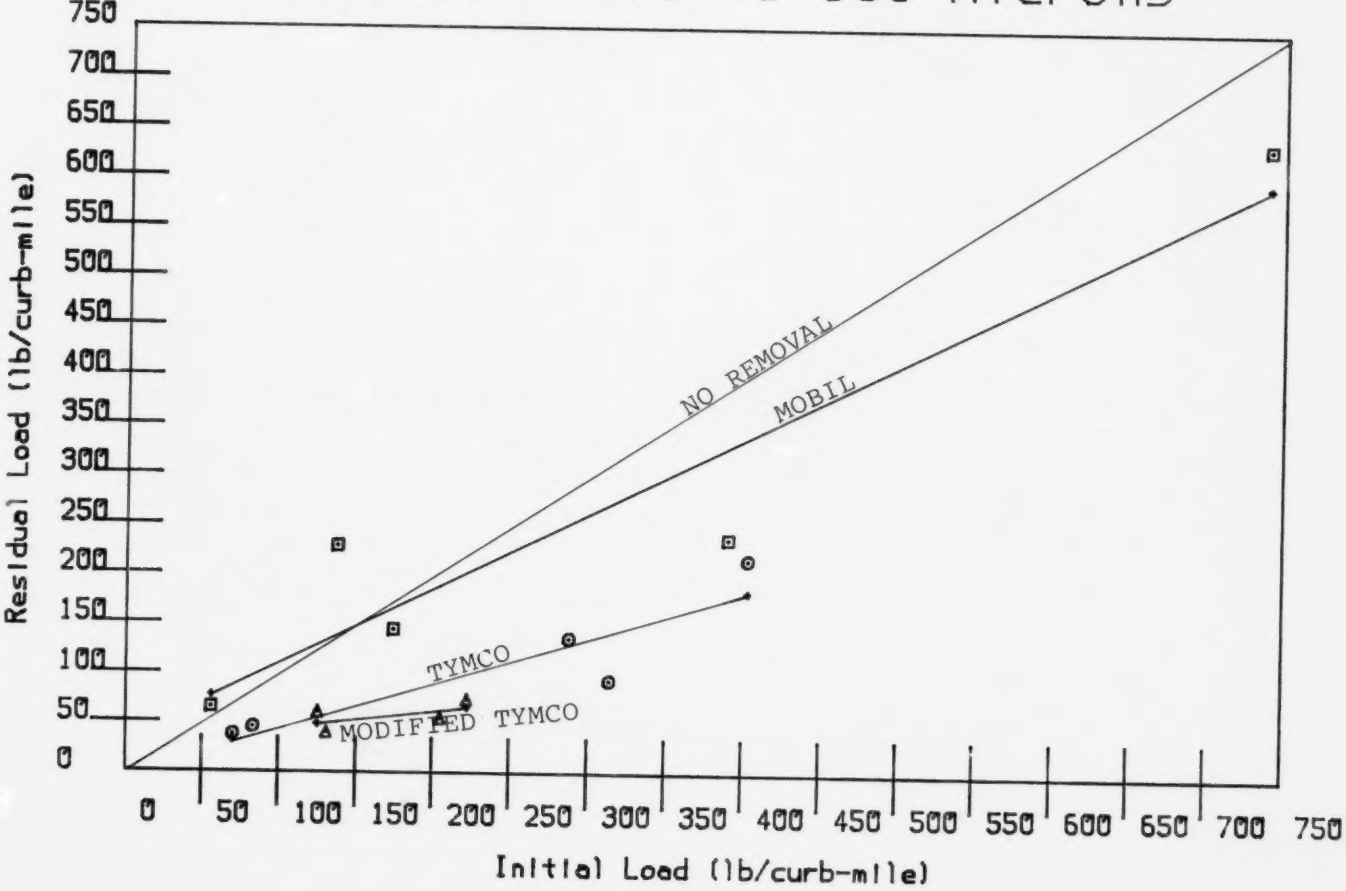
FIGURE C-24

S.E. 30th 250 to 500 Microns



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TOP OF IMAGE AREA
DROPPED HEAD, BEGIN SECTIONS HERE
BEGIN LAST LINE OF TEXT
1/8"
PAGE NUMBER
BOTTOM OF IMAGE AREA, OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
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FIGURE C-25

S.E. 30th 125 to 250 Microns

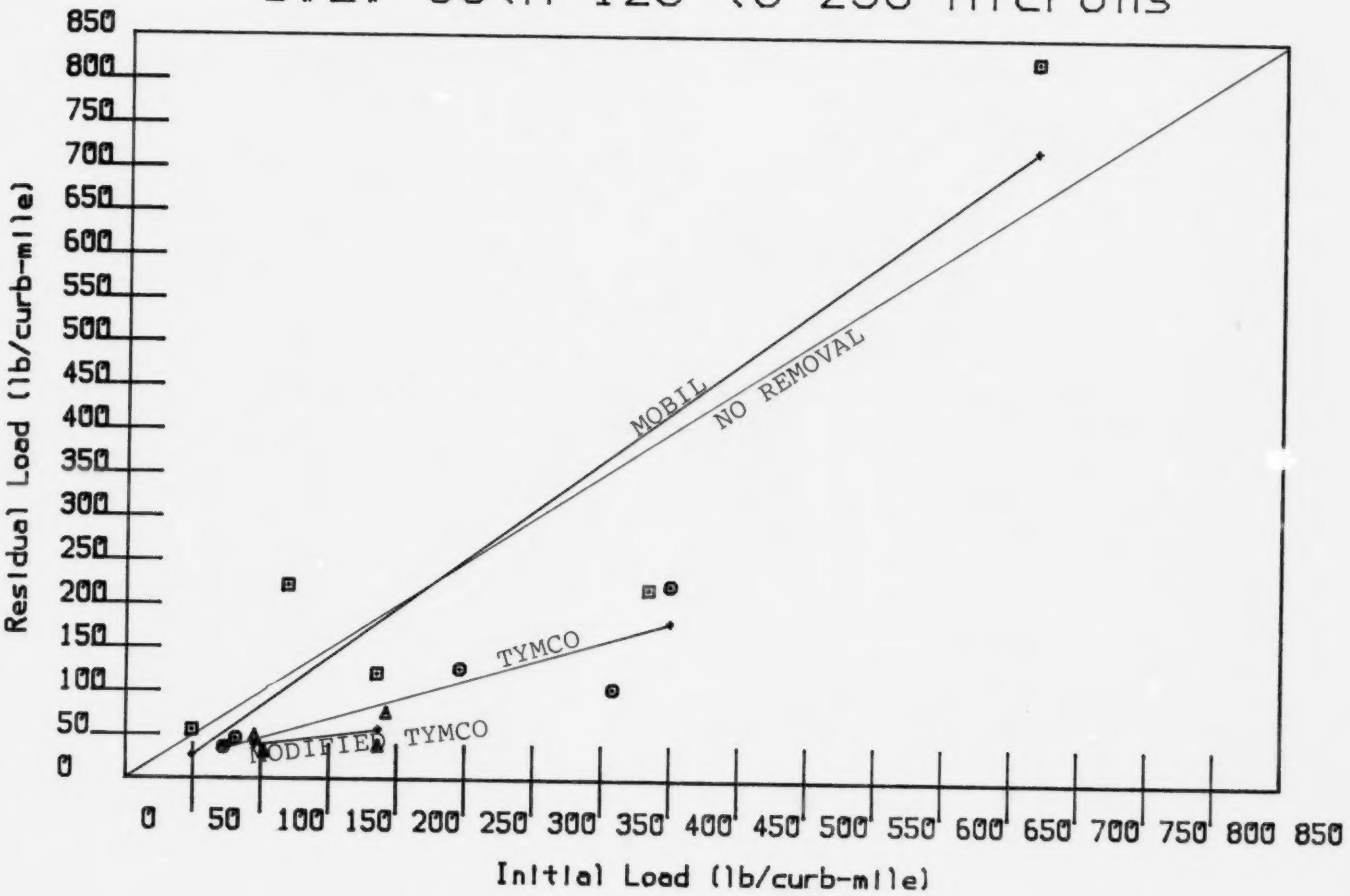

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FIGURE C-26

S.E. 30th 63 to 125 Microns

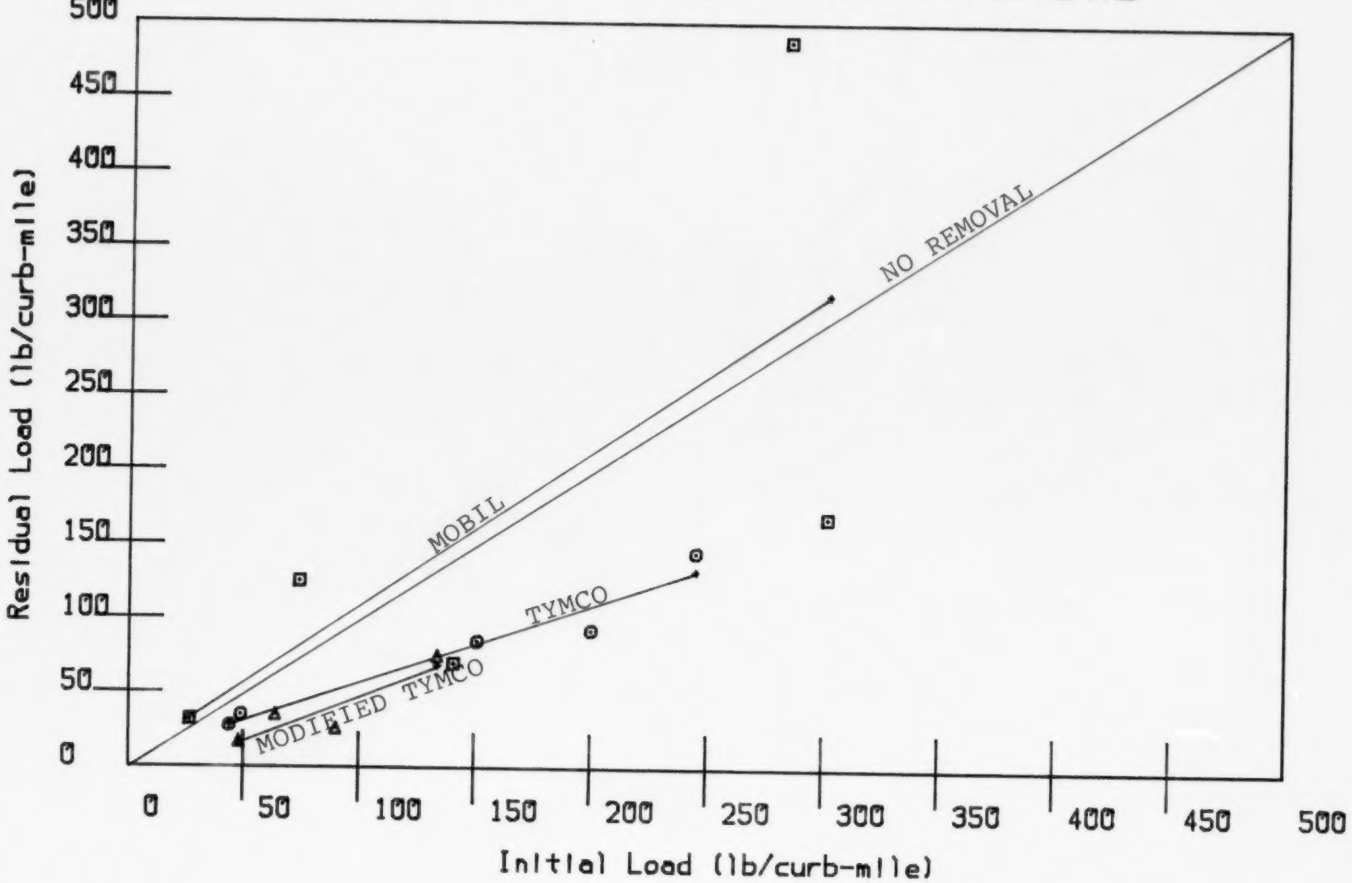

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FIGURE C-27

S.E. 30th 37 to 63 Microns

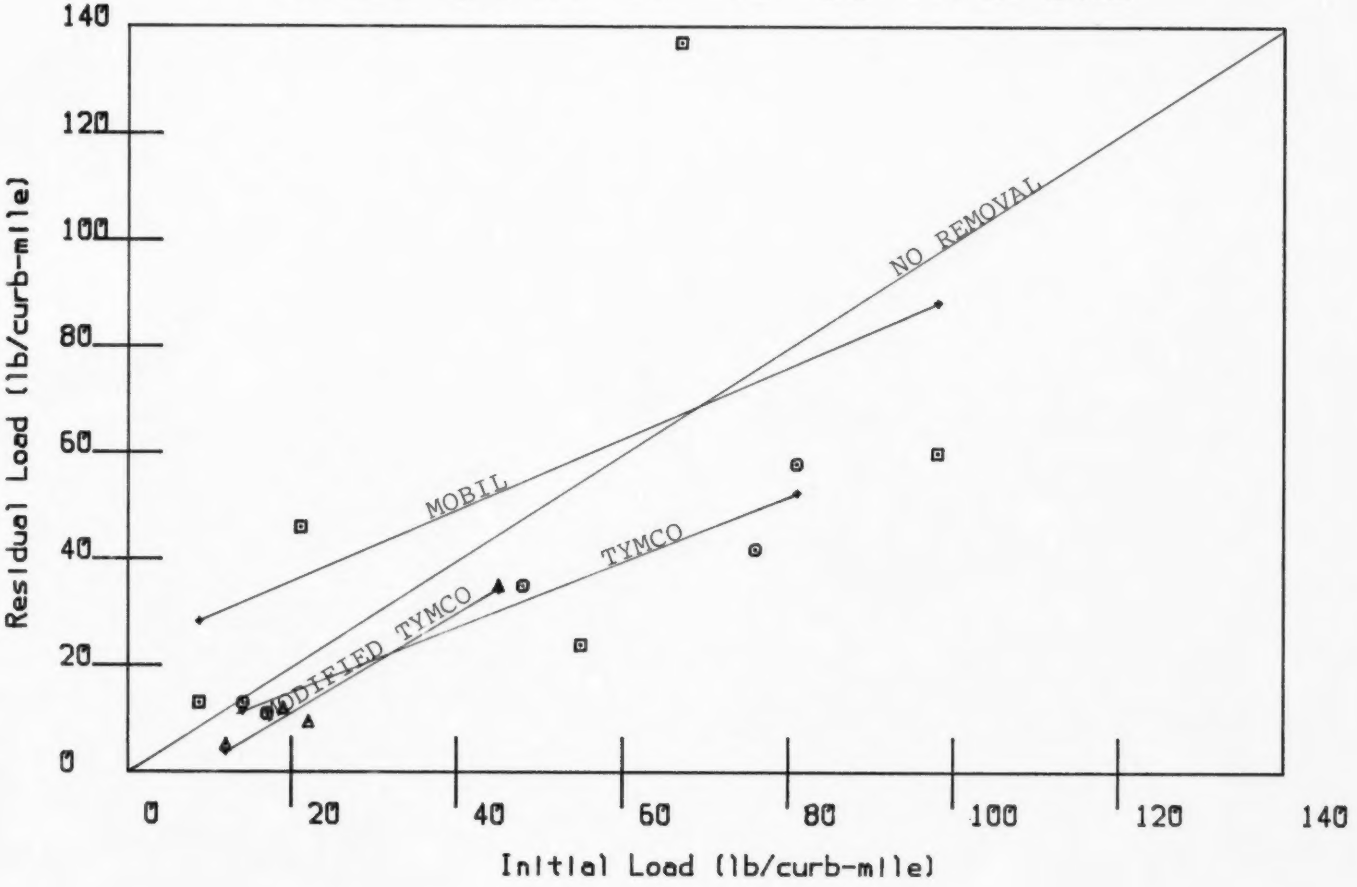

FIGURE C-28

S.E. 30th Less Than 37 Microns

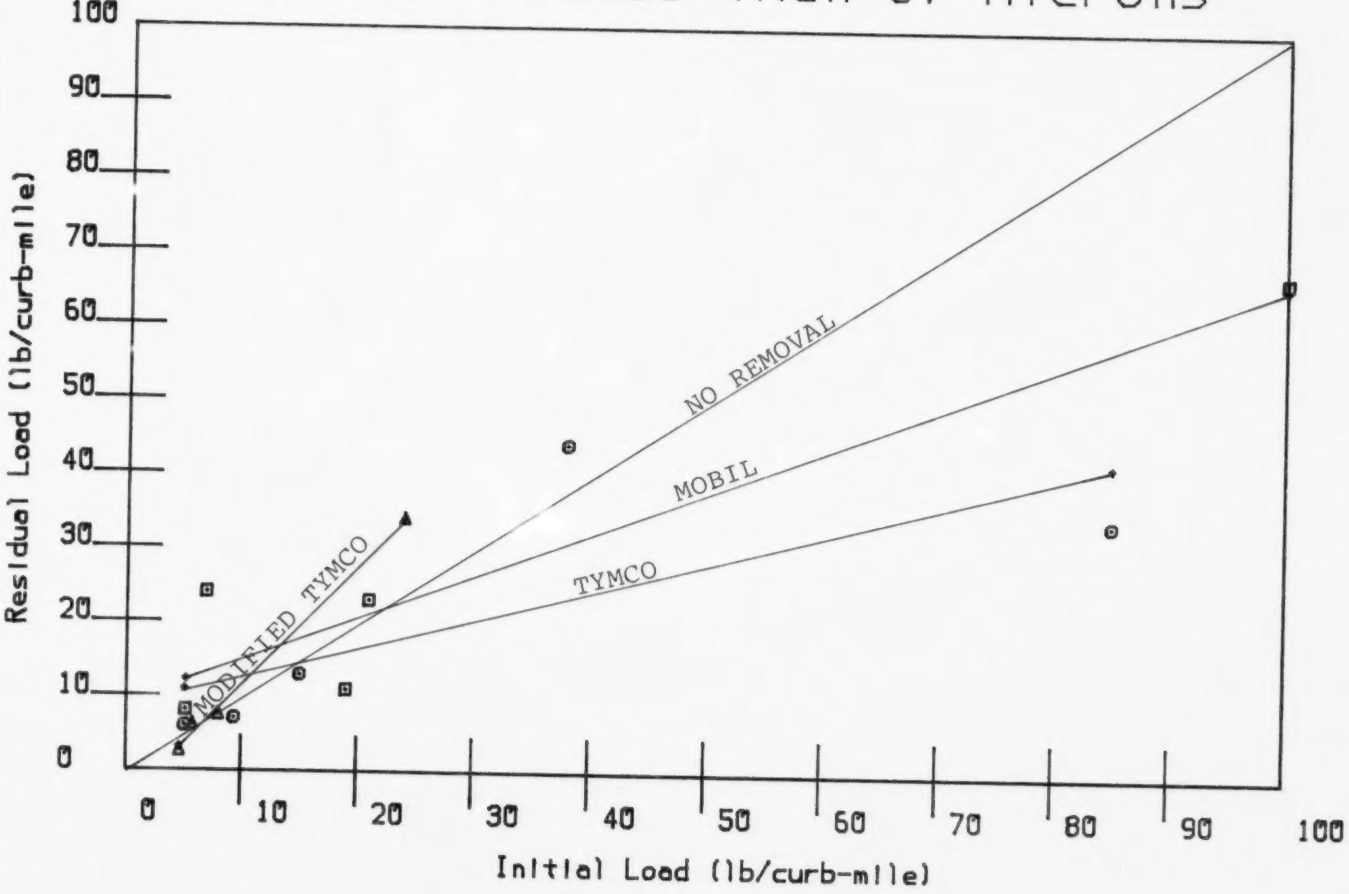

FIGURE C-29

S.E. 30th 2 to 10 Microns

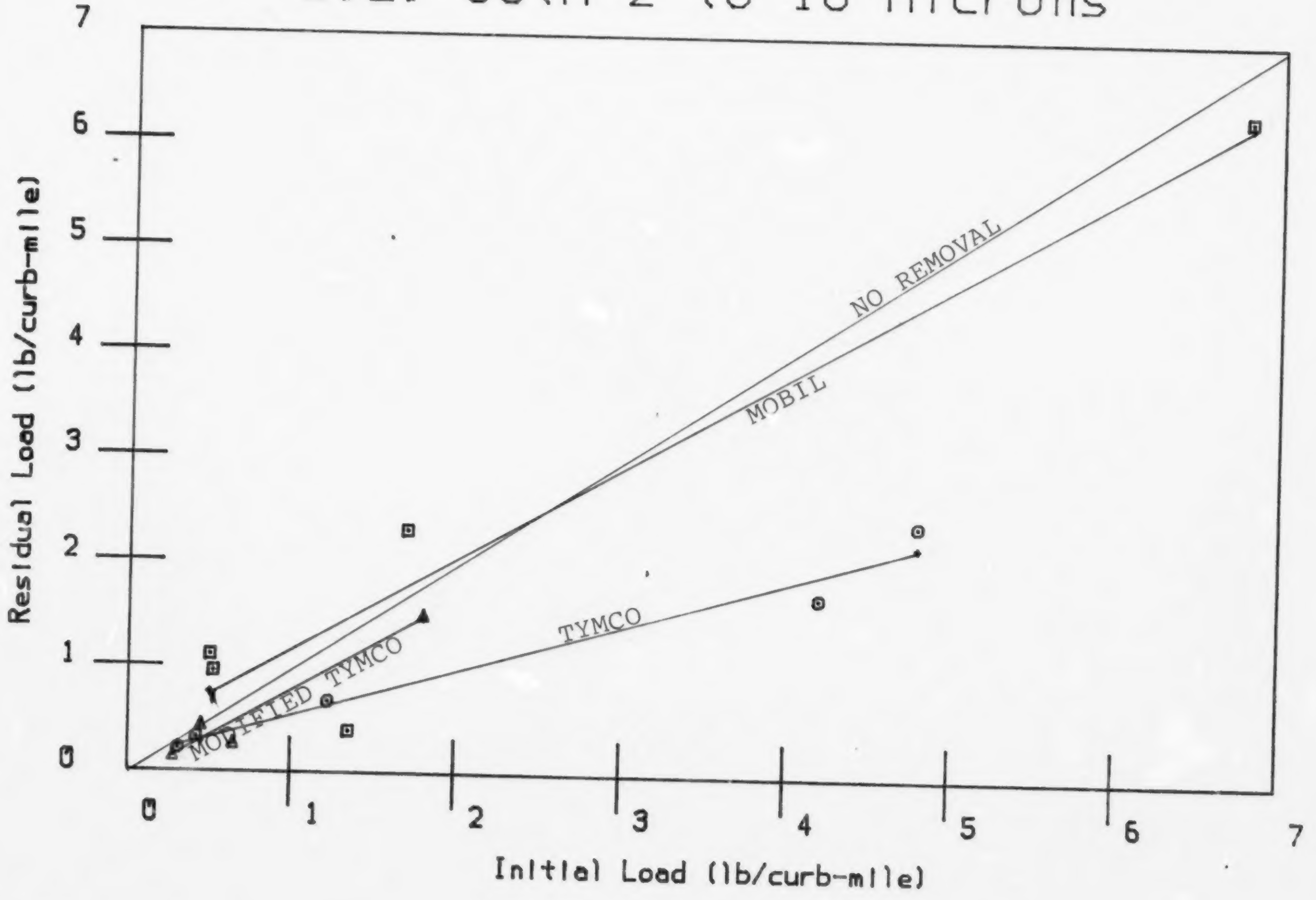

FIGURE C-30

S.E. 30th Less Than 2 Microns

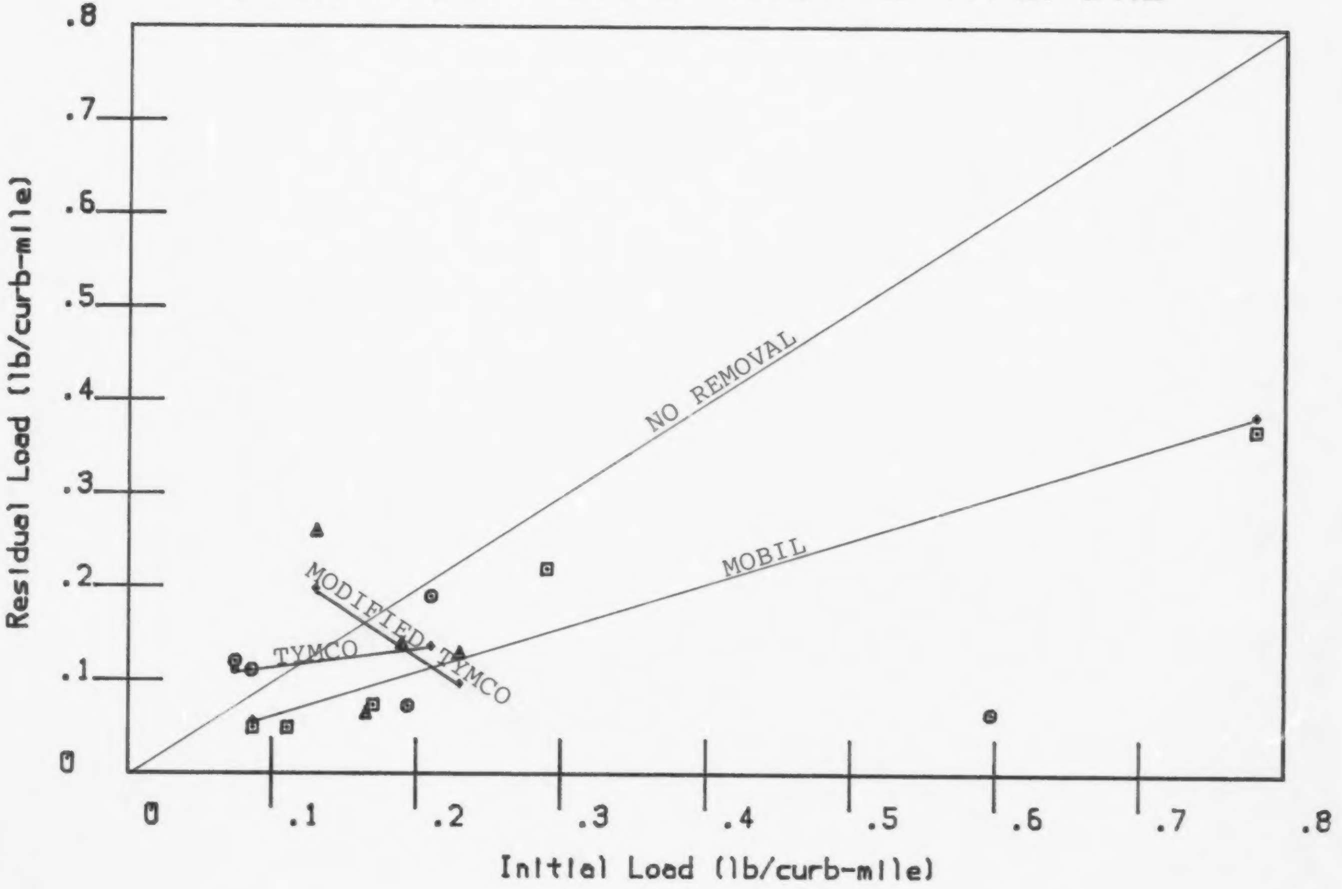

Table D-1. Surrey Downs Catchbasin Sediment Loading Observations (cubic feet)

Number	Dec 13-26 1979	Aug 8-14 1980	Jan 30 1981	Feb 26-Mar 11	Apr 21-24	Jun 16-17	Jul 17-21	Aug 17-24	Jan 18-Feb 5 1982	Minimum	Maximum	Average
506	.00	.05	.00	.00	.00	.41	.00	.09	1.56	.00	1.56	.23
507	.40	.12	1.81	1.81	1.81	2.61	1.81	2.01	3.41	.12	3.41	1.75
509	.04	.02	2.23	2.05	2.41	3.14	2.63	2.71	4.02	.02	4.02	2.14
510	.28	.24	1.28	1.42	1.53	1.42	1.62	1.56	1.70	.24	1.70	1.23
526	.30	.13	2.36	2.10	2.42	2.28	2.10	2.10	2.76	.13	2.76	1.84
527	.29	.12	6.74	6.56	7.16	6.56	6.44	6.86	7.16	.12	7.16	5.32
528	.08	.04	.19	.47	.50	.00	.31	.39	.97	.00	.97	.33
529	.06	.21	3.24	3.99	3.69	3.69	3.36	3.63	1.14	.06	3.99	2.56
531	.64	1.44	2.02	2.34	2.50	2.40	1.95	2.18	2.66	.64	2.66	2.01
532	.00	.00	.30	.21	.12	.30	.39	.15	.15	.00	.39	.18
533	.03	.14	1.15	3.02	1.15	1.15	1.56	1.01	1.30	.03	3.02	1.17
534	.80	2.20	8.69	9.01	9.01	8.81	9.17	9.01	9.41	.80	9.41	7.35
535	.18	.08	4.33	4.54	4.28	4.33	3.37	4.46	4.33	.08	4.54	3.32
536	.26	.03	4.80	4.85	4.85	4.85	4.88	4.85	4.72	.03	4.88	3.79
538	.20	.08	1.71	1.31	1.87	2.10	2.50	2.10	.32	.08	2.50	1.35
539	.21	.08	11.04	11.24	5.62	7.35	6.94	2.05	5.34	.08	11.24	5.54
540	.49	.65	6.63	6.40	3.35	6.66	6.33	1.56	.97	.49	6.66	3.67
542	.09	.15	.00	.09	.00	.24	.06	1.06	.00	.00	1.06	.19
543	.32	1.01	1.92	1.92	1.95	1.92	1.67	1.98	1.57	.32	1.98	1.58
544	.21	1.21	1.49	1.52	1.48	1.52	1.27	1.36	1.97	.21	1.97	1.34
546	.03	.17	.37	.37	.03	.37	.37	.54	.54	.03	.54	.31
547	.10	.13	2.05	1.51	1.61	1.68	2.08	1.85	2.69	.10	2.69	1.52
550	.68	.85	2.72	2.86	2.75	2.69	2.99	2.86	3.06	.68	3.06	2.38
551	.24	.34	2.41	2.04	2.21	2.38	2.72	2.04	2.21	.24	2.72	1.84
554	.10	.17	4.53	4.25	2.14	3.06	3.50	3.57	3.74	.10	4.53	2.78
555	.15	.16	1.70	2.01	.09	.71	.77	.93	1.39	.09	2.01	.88
557	.25	.31	2.81	2.96	.22	.37	.47	.56	1.87	.22	2.96	1.09
558	.31	.92	4.13	4.28	.15	.76	1.07	1.40	3.46	.15	4.28	1.83
559	.79	1.06	5.36	5.41	.79	1.72	1.06	2.51	5.25	.79	5.41	2.66
560	.64	.64	3.81	3.50	3.81	3.81	3.49	3.50	4.45	.64	4.45	3.07
561	.47	1.10	1.61	2.08	.09	.00	.19	.03	.66	.00	2.08	.69
562	.71	3.56	3.85	NA	.14	.86	1.85	1.28	NA	.14	3.85	1.75
565	.34	.00	4.32	.00	.44	1.42	1.47	1.67	5.81	.00	5.81	1.72
566	1.13	.37	6.63	6.27	.58	1.61	1.25	1.61	6.27	.37	6.63	2.86
567	.37	.19	NA	.30	.04	.00	.00	.22	.22	.00	.37	.17
568	.60	.15	1.08	1.14	.24	.84	1.57	1.35	.99	.15	1.57	.89
570	.58	.12	.00	.58	.00	.77	.15	.12	.38	.00	.77	.30
572	.34	.17	6.52	3.18	1.51	.03	.17	.10	1.34	.03	6.52	1.48
573	.49	2.46	2.32	2.46	.12	.86	.37	.62	2.09	.12	2.46	1.31
574	.20	.27	.20	.39	.08	.08	.55	.00	.20	.00	.55	.22
575	.20	2.34	1.72	1.09	.04	.12	.23	.70	.31	.04	2.34	.75
578	2.36	2.15	1.72	.43	.47	.86	.39	.64	.86	.39	2.36	1.10
580	.17	2.48	2.41	.33	2.05	2.15	2.18	.00	2.31	.00	2.48	1.56
998	.60	.60	3.03	3.24	.15	1.35	1.41	1.65	2.85	.15	3.24	1.65
Total	17	29	127	116	75	90	89	81	108	8	150	82
Maximum	2.36	3.56	11.04	11.24	9.01	8.81	9.17	9.01	9.41	.80	11.24	7.35
Average	.38	.65	2.96	2.69	1.71	2.05	2.02	1.84	2.52	.18	3.40	1.86
Count	44	44	43	43	44	44	44	44	43	44	44	44

Table D-2. Surrey Downs Inlet Sediment Loading Observations (cubic feet)

Number	Dec 13-26 1979	Aug 8-14 1980	Jan 30 1981	Feb 26-Mar 11	Apr 21-24	Jun 16-17	Jul 17-21	Aug 17-24	Jan 18-Feb 5 1982	Minimum	Maximum	Average
502	.03	.38	.03	.20	.44	.49	.35	.00	5.22	.00	5.22	.79
503	NA	.15	.16	.09	.17	.21	.10	.05	.37	.00	.37	.16
505	.04	.12	.12	.00	.16	.00	.12	.32	1.40	.00	1.40	.25
508	.42	.98	1.15	1.34	1.57	1.43	1.43	1.57	3.92	.42	3.92	1.53
511	.00	.07	1.58	1.34	1.51	1.75	1.68	1.51	7.22	.00	7.22	1.85
513	.15	.03	.00	.06	.15	.15	.36	.21	.30	.00	.36	.16
514	.15	.09	.27	.15	.24	.15	.15	.15	.60	.09	.60	.22
516	.06	.03	.81	.69	.69	.69	.69	.69	.69	.03	.81	.56
517	.03	.03	.03	.12	.06	.22	.16	.22	.22	.03	.22	.12
518	.03	.24	.12	.18	.24	.33	.39	.33	.18	.03	.39	.23
520	NA	.09	.42	.45	.60	.30	.60	.30	.45	.00	.60	.40
524	.45	.36	1.11	1.23	1.47	1.47	1.47	2.07	1.02	.36	2.07	1.18
525	.00	.00	.00	.00	.00	.00	.01	.00	.00	.00	.01	.00
530	.10	.07	.06	.04	.10	.07	.00	.07	.07	.00	.10	.06
537	.77	1.29	4.95	5.46	6.03	5.85	6.18	6.11	6.18	.77	6.18	4.76
541	.36	.85	1.06	1.27	1.27	1.36	1.51	1.58	1.21	.36	1.58	1.16
545	.26	.49	1.23	1.56	1.72	1.39	1.55	1.39	.42	.26	1.72	1.11
548	1.01	2.02	1.51	4.94	5.64	5.71	5.95	5.88	6.38	1.01	6.38	4.34
549	.32	1.29	1.49	1.32	1.97	1.81	1.42	1.81	1.29	.32	1.97	1.41
552	1.02	1.87	3.06	2.89	2.72	2.89	2.58	.07	4.08	.07	4.08	2.35
553	.22	.32	3.03	2.87	1.44	2.23	2.07	2.23	2.87	.22	3.03	1.92
556	.45	.06	4.08	4.11	4.20	4.26	4.20	1.26	2.76	.06	4.26	2.82
569	1.04	3.64	18.93	18.98	19.24	18.72	18.46	18.72	8.58	1.04	19.24	14.03
571	.35	.35	1.40	1.57	.00	.52	.70	.87	.87	.00	1.57	.74
579	1.62	2.70	.31	.39	.50	.31	.35	.39	.19	.19	2.70	.75
581	.12	.07	.30	.32	.16	.16	.23	.16	.40	.07	.40	.21
999	.03	.10	3.33	3.40	3.40	3.23	3.50	.34	.24	.03	3.50	1.95
Total	9	18	51	55	56	56	56	48	57	5	80	45
Maximum	1.62	3.64	18.93	18.98	19.24	18.72	18.46	18.72	8.58	1.04	19.24	14.03
Average	.36	.65	1.87	2.04	2.06	2.06	2.08	1.79	2.12	.20	2.96	1.67
Count	25	27	27	27	27	27	27	27	27	27	27	27

Table D-3. Surrey Downs Man Hole Sediment Loading Observations (cubic feet)

Number	Dec 13-26 1979	Aug 8-14 1980	Jan 30 1981	Feb 26- Mar 11	Apr 21-24	Jun 16-17	Jul 17-21	Aug 17-24	Jan 18- Feb 5 1982	Minimum	Maximum	Average
504	NA	.13	.00	.00	.00	.00	.00	.00	NA	.00	.13	.02
512	NA	.00	.39	.00	.79	.00	.00	.00	NA	.00	.79	.17
515	NA	NA	.00	.00	.00	.00	NA	.00	.00	NA	NA	NA
519	NA	.00	.00	.00	.00	.00	.00	.00	.00	NA	NA	NA
521	NA	.00	4.02	.00	.00	.00	.00	.00	.00	NA	NA	NA
522	NA	.00	.16	.32	.16	.00	.00	.00	.57	.00	.57	.15
523	NA	.00	.63	.38	.00	.00	.50	.00	.00	.00	.63	.19
577	10.03	15.18	15.32	15.32	13.99	15.31	25.88	15.32	20.08	10.03	25.88	16.27
Total	10	15	21	16	15	15	26	15	21	10	28	17
Maximum	10.03	15.18	15.32	15.32	13.99	15.31	25.88	15.32	20.08	10.03	25.88	16.27
Average	10.03	2.19	2.56	2.00	1.87	1.91	3.77	1.91	3.44	2.01	5.60	3.36
Count	1	7	8	8	8	8	7	8	6	5	5	5

Table D-4. Lake Hills Catchbasin Sediment Loading Observations (cubic feet)

Number	Dec 4-12 1979	Jul 23- Aug 6 1980	Jan 27-29 1981	Mar 2- Apr 1	Apr 24- May 5	Jun 19-26	Jul 14-16	Aug 27- Sep 3	Jan 20-27 1982	Minimum	Maximum	Average
505	.39	.96	2.93	1.00	6.38	1.54	1.20	1.39	1.20	.39	6.38	1.89
506	.40	.60	2.01	2.21	2.41	2.01	2.21	2.73	2.61	.40	2.73	1.91
510	.22	1.08	2.76	2.77	2.98	3.20	3.54	3.28	3.46	.22	3.54	2.59
511	.12	.20	.36	.80	.60	.80	.24	.08	1.40	.08	1.40	.51
513	.39	.12	4.28	4.47	4.67	4.32	4.32	8.32	4.47	.12	8.32	3.93
514	.59	.78	.82	1.02	1.41	1.41	2.20	2.59	1.61	.59	2.59	1.38
516	.00	.00	.00	.27	.27	.00	.00	.19	.08	.00	.27	.09
517	.04	.58	.81	.93	1.12	.73	1.89	1.12	1.31	.04	1.89	.95
519	.37	.18	1.39	1.69	1.76	1.68	1.61	1.69	2.05	.18	2.05	1.38
520	1.04	.42	2.66	2.20	2.62	3.32	2.41	2.62	2.62	.42	3.32	2.21
521	1.16	1.35	1.62	1.35	1.74	1.16	1.39	1.35	1.16	1.16	1.74	1.36
524	1.14	.76	2.93	3.43	3.62	4.19	3.50	3.62	4.57	.76	4.57	3.08
526	.58	.58	2.43	2.32	2.12	2.51	2.55	2.59	2.51	.58	2.59	2.02
528	1.60	1.14	4.83	5.52	4.15	5.06	5.29	5.75	7.57	1.14	7.57	4.54
543	.00	.04	.00	.00	NA	.00	.00	.00	.00	.00	.04	.01
544	.02	.04	.00	.00	NA	.00	.00	.00	.00	.00	.04	.01
545	.00	.39	.00	.00	NA	.00	.00	.12	.12	.00	.39	.08
546	.04	.00	.00	.00	NA	NA	.00	.00	.12	.00	.12	.02
547	.00	1.28	.00	.85	NA	1.20	.90	1.71	.00	.00	1.71	.74
548	.20	.04	2.12	1.77	NA	2.28	2.00	1.96	1.96	.00	2.28	1.54
550	.00	.08	.00	.00	NA	.00	.00	.04	.00	.00	.08	.01
551	.00	.00	.31	.00	NA	.00	.35	.15	.39	.00	.39	.15
552	.00	.00	.00	.00	NA	.00	.00	.00	.00	.00	.00	.00
553	.00	.04	.04	.00	NA	.00	.00	.15	.00	.00	.15	.03
554	.00	.00	NA	NA	NA	.00	NA	NA	.00	.00	.00	.00
555	.00	.00	.08	.00	NA	.00	.08	.27	.12	.00	.27	.07
556	.04	.00	.08	.00	NA	.00	.00	.12	.00	.00	.12	.03
560	.08	.28	.16	.00	NA	.36	.28	.08	.16	.00	.36	.17
561	.04	.19	.54	.85	NA	1.23	.63	.46	1.04	.00	1.23	.62
564	.08	1.58	2.46	2.10	NA	2.49	2.30	2.49	2.49	.00	2.49	2.00
565	.00	.00	.00	.09	NA	.00	.09	.09	.09	.00	.09	.04
566	.21	.63	.17	.42	NA	.34	.38	.34	.34	.00	.63	.35
568	.08	.12	.00	.08	NA	.39	.08	.77	.77	.00	.77	.29
570	.00	.04	.00	.08	NA	.00	.20	.20	.00	.00	.20	.06
571	.04	.29	.51	.55	NA	.55	.33	.55	.33	.00	.55	.39
573	.04	.08	.46	.04	NA	.46	.46	.46	.46	.00	.46	.31
574	.08	.08	.04	.00	NA	.19	.08	.08	.15	.00	.19	.09
576	.08	.19	.89	1.16	NA	1.16	.66	1.16	1.35	.00	1.35	.83
577	.07	.07	.13	.17	NA	.17	.13	.20	.10	.00	.20	.13
578	.02	.17	.40	.34	NA	.34	.54	.51	.67	.00	.67	.37
579	1.41	.35	.14	NA	.50	.57	1.06	NA	1.88	.00	1.88	.84
580	NA	.03	1.24	NA	1.28	1.28	1.31	NA	1.11	.00	1.31	1.04
582	.39	.39	1.54	NA	1.93	2.12	2.04	2.31	1.35	.00	2.31	1.51
584	.08	.04	.29	NA	.29	.50	.21	.42	.29	.00	.50	.27
588	.40	.12	.71	NA	.48	NA	.51	.00	.40	.00	.71	.37
589	.04	.11	.18	NA	.32	NA	.50	.07	.25	.00	.50	.21
591	.12	.08	.00	.08	.46	.66	.46	NA	.73	.00	.73	.32
593	.39	.39	.35	.78	.31	.78	.43	.59	.39	.31	.78	.49
596	.20	.12	.00	.00	.20	.00	.08	.00	.39	.00	.39	.11

Table D-4. Lake Hills Catchbasin Sediment Loading Observations (cubic feet) **(cont.)**

Number	Dec 4-12 1979	Jul 23–Aug 6 1980	Jan 27-29 1981	Mar 2–Apr 1	Apr 24–May 5	Jun 19-26	Jul 14-16	Aug 27–Sep 3	Jan 20-27 1982	Minimum	Maximum	Average
597	.77	.96	.69	.77	.77	.58	.46	.58	.77	.46	.96	.71
598	.00	.04	.20	.00	.20	.00	.00	.08	.00	.00	.20	.06
599	.20	.48	.64	.44	.44	1.04	.88	.96	1.04	.20	1.04	.68
601	.08	.19	.08	.08	.00	.27	.08	.00	.08	.00	.27	.09
603	.12	.19	.00	.00	.23	.00	.00	.04	.00	.00	.23	.06
607	.08	.20	.20	.48	.60	.00	.00	.00	.20	.00	.60	.20
608	.37	.37	.37	.37	.48	.00	.26	.44	.18	.00	.48	.31
609	.26	.19	1.23	1.12	.00	1.50	1.08	1.38	.37	.00	1.50	.79
612	.29	.54	2.39	2.50	2.86	2.14	1.96	2.50	2.68	.29	2.86	1.98
614	NA	NA	2.41	2.52	2.52	2.66	2.55	2.63	2.66	.00	2.66	2.56
616	.56	.15	1.61	1.68	1.61	1.68	1.68	1.50	1.68	.15	1.68	1.35
618	.00	.00	.00	.00	.00	.20	.08	.00	.00	.00	.20	.03
619	.04	.20	.79	.79	.98	1.38	.71	.51	1.38	.04	1.38	.75
621	.04	.28	.12	.52	NA	.51	.16	.12	.71	.00	.71	.31
623	.04	.04	.00	.00	NA	.00	.00	.00	.00	.00	.04	.01
625	.00	.04	.08	.00	NA	.12	.40	.00	.00	.00	.40	.08
627	.04	.04	.20	.20	NA	.20	.04	.00	.78	.00	.78	.19
629	.04	.08	.08	.31	NA	.70	.74	1.09	.31	.00	1.09	.42
630	.04	.08	.12	.41	NA	2.89	2.76	3.09	2.68	.00	3.09	1.51
631	.04	.19	.00	.00	.00	.00	.19	.96	.00	.00	.96	.15
632	.19	.39	.58	.69	.58	.77	.89	.96	.89	.19	.96	.66
634	.08	.12	.77	.96	NA	.96	.62	.77	1.16	.00	1.16	.68
Total	15	21	55	53	53	67	64	70	72	8	96	55
Maximum	1.60	1.58	4.83	5.52	6.38	5.06	5.29	8.32	7.57	1.16	8.32	4.54
Average	.22	.30	.79	.83	1.39	.98	.91	1.05	1.01	.11	1.35	.77
Count	69	70	70	64	38	68	70	67	71	71	71	71

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Table D-5. Lake Hills Inlet Sediment Loading Observations (cubic feet)

Number	Dec 4-12 1979	Jul 23-Aug 6 1980	Jan 27-29 1981	Mar 2-Apr 1	Apr 24-May 5	Jun 19-26	Jul 14-16	Aug 27-Sep 3	Jan 20-27 1982	Minimum	Maximum	Average
502	.04	.14	.00	.07	.07	.07	.14	.07	.00	.00	.14	.07
507	.09	.09	.47	.31	.41	NA	.00	.22	.22	.00	.47	.23
508	.00	.10	.03	.00	.00	.00	.00	.13	.03	.00	.13	.03
509	.00	.03	.00	.00	.00	.00	.00	.07	.00	.00	.07	.01
512	.03	.10	.30	.30	.17	.30	.30	.30	.37	.03	.37	.24
515	.00	.03	.00	.07	.00	.00	.00	.17	.00	.00	.17	.03
518	.00	.07	.00	.00	.00	.00	.00	.00	.00	.00	.07	.01
522	.03	.07	.00	.00	.00	.17	.10	.17	.13	.00	.17	.07
525	.10	.34	.10	.10	.27	.10	.37	.27	.07	.07	.37	.19
527	.13	.67	.13	.20	.13	.20	.24	.20	.30	.13	.67	.25
529	.00	.03	.17	.10	.07	.07	.00	.17	.07	.00	.17	.08
531	.00	.07	.00	.18	.32	.18	.32	.36	.18	.00	.36	.18
532	.00	.07	.00	.00	.00	.00	.00	.03	.00	.00	.07	.01
536	.00	.00	.00	.07	.07	.00	.10	.34	.10	.00	.34	.07
542	.29	.84	1.80	1.59	1.67	1.46	1.38	1.67	1.04	.29	1.80	1.30
549	.38	.38	.30	.36	NA	.45	.30	.45	.08	.08	.45	.34
557	.13	.10	.03	.24	NA	.17	.24	.03	.00	.00	.24	.12
559	.00	.17	.00	.07	NA	NA	NA	NA	.00	.00	.17	.05
562	.03	.10	.00	.00	NA	.03	.00	.03	.00	.00	.10	.02
563	.02	.27	.27	.20	NA	.20	.37	.20	.00	.00	.37	.19
567	.03	.03	.00	.00	NA	.00	.30	.00	.00	.00	.30	.05
569	.07	.17	.03	.10	NA	.17	.03	.17	.17	.03	.17	.11
572	.03	.07	.00	.00	NA	.07	.00	.03	.00	.00	.07	.03
575	.03	.00	.00	NA	NA	.00	NA	.00	.00	.00	.03	.01
577	.07	.07	.13	.17	NA	.17	.13	.20	.10	.07	.20	.13
578	.02	.17	.40	.34	NA	.34	.54	.51	.67	.02	.67	.37
580	NA	.03	1.24	NA	1.28	1.28	1.31	NA	1.11	.03	1.31	1.04
585	.07	.03	.20	NA	.13	.20	.17	.20	.00	.00	.20	.13
587	1.54	1.16	2.43	NA	2.70	2.12	1.58	1.93	2.70	1.16	2.70	2.02
590	.03	.55	.87	NA	.96	.82	.82	1.09	.68	.03	1.09	.73
592	.77	.96	2.47	2.66	3.24	3.24	2.66	NA	3.47	.77	3.47	2.43
594	.79	1.77	5.14	5.42	5.49	5.49	.59	5.50	5.10	.59	5.50	3.92
602	.28	1.19	3.30	3.57	3.57	3.77	4.09	3.77	4.17	.28	4.17	3.08
604	.08	.27	.08	.08	.11	.27	.11	.19	NA	.08	.27	.15
606	.06	.14	.14	.27	.08	.05	.11	.41	.05	.05	.41	.15
610	.00	.00	.00	.03	.00	.00	.00	.00	.00	.00	.03	.00
613	NA	NA	.77	.70	.58	.70	.66	.58	.35	.35	.77	.62
615	.60	.60	.78	.90	1.05	.90	.81	.96	1.05	.60	1.05	.85
617	.03	.09	.44	.22	.38	.38	.44	.53	.31	.03	.53	.31
620	.20	.78	.98	.98	.98	1.26	1.10	1.26	.39	.20	1.26	.88
622	.12	1.39	1.99	1.39	NA	2.19	1.43	1.79	.60	.12	2.19	1.36
624	.08	.78	1.10	1.37	NA	1.57	1.61	1.37	1.37	.08	1.61	1.16
626	.24	.40	1.27	.84	NA	.84	.79	.84	.84	.24	1.27	.76
628	.12	.98	2.22	2.54	NA	2.73	2.58	2.73	2.93	.12	2.93	2.10
633	.16	.79	1.95	1.95	1.95	2.34	2.18	1.95	2.54	.16	2.54	1.76
Total	7	16	32	27	26	34	28	31	31	6	41	28
Maximum	1.54	1.77	5.14	5.42	5.49	5.49	4.09	5.50	5.10	1.16	5.50	3.92
Average	.16	.37	.70	.68	.86	.80	.65	.74	.71	.12	.92	.61
Count	43	44	45	40	30	43	43	42	44	45	45	45

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Table D-6. Lake Hills Man Hole Sediment Loading Observations (cubic feet)

Number	Dec 4-12 1979	Jul 23-Jan Aug 6 1980	27-29 1981	Mar 2- Apr 1	Apr 24-Jun May 5	19-26Jul	14-16	Aug 27-Jan Sep 3	20-27 1982	Minimum	Maximum	Average
503	.00	.00	14.28	15.83	14.40	10.17	14.70	13.01	9.61	.00	15.83	10.22
504	.40	.13	.00	.00	1.39	.40	.00	.00	.26	.00	1.39	.29
523	2.51	1.26	1.13	2.14	2.14	4.65	3.02	2.77	3.39	1.13	4.65	2.56
530	5.67	1.42	.14	.28	.99	4.82	.00	.00	3.20	.00	5.67	1.84
533	1.89	1.01	3.52	4.15	1.76	4.77	3.02	4.52	2.26	1.01	4.77	2.99
534	NA	.00	.00	.00	.00	.00	.00	.35	.00	.00	.35	.04
535	5.66	.71	8.13	7.71	7.49	7.70	8.34	7.71	9.33	.71	9.33	6.97
537	.13	.38	.25	.00	.00	.00	.13	.00	1.26	.00	1.26	.24
538	.25	.25	.50	.00	.13	.00	.38	.00	.63	.00	.63	.24
539	1.26	1.26	6.28	1.26	1.63	1.88	2.01	1.89	1.43	1.26	6.28	2.10
540	NA	.00	.00	NA	.00	.00	.00	NA	.00	.00	.00	.00
541	NA	.29	9.62	11.06	10.58	9.62	10.29	9.62	12.10	.29	12.10	9.15
579	1.41	.35	.14	NA	.50	.57	1.06	NA	1.88	.14	1.88	.84
581	5.65	.71	5.51	NA	3.96	4.10	4.95	4.81	2.64	.71	5.65	4.04
583	NA	NA	NA	NA	NA	1.63	3.27	1.63	6.66	1.63	6.66	3.30
Total	25	8	50	42	45	50	51	46	55	7	76	45
Maximum	5.67	1.42	14.28	15.83	14.40	10.17	14.70	13.01	12.10	1.63	15.83	10.22
Average	2.26	.55	3.54	3.86	3.21	3.35	3.41	3.56	3.64	.46	5.10	2.99
Count	11	14	14	11	14	15	15	13	15	15	15	15

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Table D-7. RELATIVE CATCHBASIN SEDIMENT QUALITY (LAKE HILLS)

CB#	Sampling Date	(1)	(2)	Total Solids(%)	mg constituent/kg total solids COD	TKN	Phos	Pb	Zn
524	3-20-80	X		19.1	42,400	1440	199	880	318
535	3-20-80	X		70.5	15,700	55.6	28.4	15.5	37.9
578	3-20-80	X		5.31	267,000	11,200	2170	2930	595
626	3-20-80	X		13.8	34,100	4630	905	1880	906
616	3-20-80	X		26.2	14,500	2130	282	604	226
592	12-27-79		X	91 mg/l	263,786	5495	3571	879	13,077
616	12-27-79		X	88 mg/l	306,818	11,136	1500	795	511
626	12-27-79		X	124 mg/l	193,548	9677	1758	564	637
524	12-27-79		X	85 mg/l	282,353	55,647	7506	1588	212
528	12-28-79		X	111 mg/l	729,730	19,820	2901	1261	946
535	12-27-79		X	272 mg/l	897,059	11,176	25,092	404	801
549	12-28-79		X	34 mg/l	647,069	35,000	2412	2647	971
564	12-28-79		X	49 mg/l	663,265	10,204	1592	1633	1796
578	12-28-79		X	158 mg/l	569,620	35,443	4367	2848	797
582	12-28-79		X	150 mg/l	133,833	4667	900	800	247
592	12-27-79	X		54.0	5115	794	12.8	580	166
616	12-27-79	X		13.6	213	342	1.7	236	159
626	12-27-79	X		40.6	585	878	24.9	278	146
524	12-27-79	X		46.2	439	1020	31.4	262	93.0
528	12-28-79	X		427	312	778	13.0	149	53.5
535	12-27-79	X		79.5	55.1	56.0	18.9	13.0	37.0
549	12-28-79	X		63.7	315	353	5.1	407	123
563	12-28-79	X		60.7	1020	1470	11.6	507	211
578	12-28-79	X		28.8	892	2010	24.6	465	104
582	12-28-79	X		59.7	412	560	8.45	479	120

(1) sediment sample

(2) supernatant sample

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Table D-7. RELATIVE CATCHBASIN SEDIMENT QUALITY (SURREY DOWNS)

CB#	Sampling Date	(1)	(2)	Total Solids(%)	mg constituent/kg total solids COD	TKN	Phos	Pb	Zn
510	3-19-80	X		9.29	269,000	9710	2020	5070	540
548	3-19-80	X		19.2	121,000	3960	411	806	137
559	3-19-80	X		56.6	92,700	7910	168	1325	245
531	3-19-80	X		5.75	489,000	12,200	2124	5153	1195
534	3-19-80	X		5.99	445,000	27,500	3720	2890	1000
508	2-4-80		X	87 mg/l	206,897	9655	632	345	919
510	2-4-80		X	40 mg/l	500,000	14,000	3875	1500	1925
524	2-4-80		X	114 mg/l	175,439	12,281	2737	263	298
548	2-4-80		X	116 mg/l	189,655	12,069	629	517	371
566	2-4-80		X	100 mg/l	110,000	5600	280	400	500
526	2-14-80		X	1470 mg/l	42,178	1109	255	6258	2544
531	2-14-80		X	144 mg/l	145,833	4375	451	694	576
534	2-14-80		X	399 mg/l	107,769	12,807	814	326	241
559	2-14-80		X	215 mg/l	144,186	2605	605	1209	465
578	2-14-80		X	4160 mg/l	293,269	7356	73,798	1346	685
508	2-4-80	X		8.08	190,000	13,500	1510	2080	682
510	2-4-80	X		27.4	26,400	3890	321	1490	472
524	2-4-80	X		50.7	63,300	1790	292	349	153
548	2-4-80	X		44.1	112,000	1040	199	299	108
566	2-4-80	X		73.0	39,900	154	250	90.6	117
526	2-14-80	X		70.5	24,300	10,200	54.3	517	177
531	2-14-80	X		4.60	456,000	6380	515	3510	725
534	2-14-80	X		16.25	492,000	4510	136	954	317
559	2-14-80	X		75.4	24,300	880	23.9	477	107
578	2-14-80	X		26.0	108,000	809	129	790	365

(1) Sediment sample
(2) Supernatant sample

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APPENDIX E
SAMPLING PROCEDURE

STORMWATER SAMPLING

This appendix describes the procedures and techniques used during the Bellevue urban runoff study for collecting composite flow and proportional stormwater runoff samples. The sampled basins (Surrey Downs and Lake Hills) are described in Section 3 of this report.

The equipment installed at each site for flow-weighted composite stormwater monitoring consists of a Manning composite sampler (S-3000), a Manning flowmeter with an ultrasonic stage sensor (UF-1100) and a 12 volt power converter. The samplers were factory modified for priority pollutant sampling. All surfaces contacting the sample are either glass or Teflon. Special cleaning procedures were developed for collecting priority pollutant samples. These special procedures are described by METRO in their report.

The sampler is triggered at predetermined increments of flow by the flowmeter. These flow increments need to be small enough so small runoff events will be adequately represented by enough samples. Conversely, the sample container should be large enough so that large events do not cause the sample volume to exceed the storage capacity. A 30 to 50 gallon (110 to 190 liter) polypropylene reservoir with a five gallon (19 liter) glass inner reservoir for priority pollutant analysis has been found to be adequate. In addition, the increment of flow selected for subsampling should not be so small that during peak flows the cycling capacity of the sampler is exceeded. For instance, in the case where the peak flow is expected to be less than ten cubic feet per second (cfs) (280 liters/second), a sampling increment of 600 cubic feet (17,000 liters) would produce one subsample per minute at ten cfs (280 liters/second). It is necessary to determine the cycle time of the sampler in the field. At the Bellevue sites, it was expected that maximum flows would not exceed ten cfs (280 liters/second) and the sampler cycle time was 40-45 seconds. Flow increments of 300 and 500 cubic feet (8500 and 14,000 liters) were therefore used. At 300 cubic foot (8500 liter) subsampling increments, peak flows would cause the cycle time to be exceeded. This increment was used to obtain more subsamples when small events were expected. The flow has exceeded ten cfs (280 liters/second) at the Lake Hills site on several occasions, briefly exceeding the cycling capacity of the sampler during the peak flows.

The flowmeters use an ultrasonic transducer to sense relative stage. Stage is converted to discharge by a programmed microprocessor in the flowmeter and presented on a circular flow chart as a percentage of maximum rated flow. The microprocessor is programmed from a stage/discharge rating developed by the USGS (Ebbert, Poole, and Payne, 1983). These ratings are described in their report. Weekly or daily flow charts are selected based on weather predictions, with daily charts preferred for runoff events. The flowmeter totals the flow in 100 cubic foot (2800 liter) increments and triggers the sampler at the selected flow increment.

The subsample volume is adjustable up to a maximum of about 450 ml. To ensure adequate samples from small events, the subsample volume is adjusted to near maximum. The intake hose for the sampler is securely attached to the bottom of the concrete drain pipe with two anchor bolts. Profiles of suspended solids as a function of depth in the pipe during flow have indicated that solids are evenly distributed, due to the turbulent flow, so that no correction factor is necessary.

The samplers can be used with 12 volt batteries as a power source. However, the motorcycle batteries supplied with the samplers are inadequate. A 12 volt power converter was used in conjunction with a large capacity (90 amp-hour, or greater) battery.

Calibration of the flowmeters required the use of an artificial stage target set at zero and 100 percent of rated flow. Comparisons of discharge records obtained from the flowmeters and discharge records from the USGS equipment and the Manning flowmeters indicated that the Manning flowmeters were somewhat less accurate. For this reason, the USGS flow data were used whenever possible. The flowmeters are adequate for triggering the sampler and for providing a back-up record of flow.

Entries on a station log were made at each visit to the stations, describing all maintenance and calibration activities.

Storm samples were removed from the samplers as soon as possible after storms, typically within two or three hours. Samples are kept on ice until processed. A storm processing log was kept for each storm. Conductivity, pH, and turbidity were measured at the City of Bellevue water quality laboratories. Subsamples were preserved and sent to a contract lab in Seattle (Am Test, Inc.) for the chemical analyses. Analytical methods are in accordance with "Methods for Chemical Analysis of Water and Wastes," EPA-600/4-79-020. These constituent analyses and the rainfall/runoff data were used to calculate mass loads for storm events.

It was possible with this sampling arrangement to obtain representative storm samples for 80 to 100 percent of the runoff events. When sampling failures occurred during a runoff event, partial samples representative of a part of the storm were usually collected. Analyses of the sample volumes and the hydrographs determined the times of sampling. The flow charts had event markers for each sample pulse; however, with short sampling increments, individual event marks were not always discernible.

A quality control program for chemical analysis of runoff samples and street dirt samples was completed. The USGS national laboratory processed duplicates of samples sent to the contract lab. Discussion of the QC program is included in the USGS report.

STREET SURFACE PARTICULATE SAMPLING AND EXPERIMENTAL DESIGN

The sampling procedures described in this appendix were mostly developed in a previous study: "Demonstration of Nonpoint Pollution Abatement Through Improved Street Cleaning Practices," (Pitt, 1979).

Equipment Selection and Sampling Effectiveness

As part of the Bellevue experimental design efforts, various vacuum, hose and gulper attachment combinations were tested. Relative air flows and suction pressures in the hose were monitored for different test set-ups. Both one and two vacuum configurations and 1.5 inch (38 mm) hoses in lengths varying from 10 to 35 feet (3 to 11 meters) were tested, along with a Vacu-Max unit. The standard "reference" system was two vacuums and a 35 foot (11 meter) hose. The best suction and higher air velocities were observed with two vacuums and short hose lengths (10 feet, or 3 meters), but the short hose length would require that the vacuums be dismounted from the truck at each subsampling location. This would require a substantial increase in time and labor. The longer hose, with the two vacuums, was judged adequate, and resulted in great cost and time savings.

Twelve street dirt sampling effectiveness tests were conducted throughout the project for several weather and street surface conditions. The street dirt sampling effectiveness tests were conducted in an area about ten feet (3 meters) along the curb to the street's center line. This area was completely vacuumed using a single pass of the standard sampling equipment. The sample was removed from the vacuum canisters and stored for later processing. The same area was then immediately vacuumed a second time using the same procedures. Again, the second vacuumed sample was removed for storage. The same area was finally sprayed with a water spray and wet vacuumed to remove all runoff. The wetting and wet vacuuming were repeated again, if necessary, until the street surface was thoroughly cleaned. This sampling indicated the street surface loadings that remained on the street after the normal single pass sample collection. This is not an indication of how much more material would wash off the street during rain events when compared with the street sampling. Very few rain events would be as effective in cleaning the street as the spraying and wet vacuuming procedures used in these tests. These tests were mainly used to confirm that the single pass dry vacuum procedures removed more material than the rain events and the mechanical street cleaning equipment.

Table E-1 summarizes the results of these tests. The initial street surface loads varied over a wide range of conditions (from 100 to 1500 lbs/curb-mile, or 28 to 430 g/curb-meter). Tests were also conducted with wet and dry street surface moisture conditions and on streets having good to moderately rough textures. The first dry vacuum sample collected about 40 to 85 percent of the total absolute street surface load. The percent recovery was slightly better for the higher street surface loads and somewhat less for the more damp street surfaces. The sample recovery with the first dry vacuum pass was much greater for the larger particle sizes than for the smaller

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Table E-1 SAMPLING EFFECTIVENESS TEST RESULTS

					Percent of absolute street loading removed by first dry vacuuming						
date	test area	street moisture	street texture	total solids loading (lb/curb-mi)	total solids (%)	COD	TKN	T Phos	Lead	Zinc	Remaining total solids loading (lb/curb-mi)
9/5/80	Surrey Downs	—	——	534	75%	59%	85%	47%	50%	57%	134
1/16/81		dry	smooth	451	79	84	58	57	57	54	95
3/15/81		wet	smooth	223	69	51	37	39	45	40	136
4/16/81		dry	smooth	419	64	44	41	41	41	36	151
7/29/81		dry	sl. rough	1460	72	72	58	40	61	61	409
1/28/82		wet	sl. rough	432	69	23	20	53	38	37	133
2/3/82		wet	smooth	400	53	26	19	47	18	32	188
7/29/80	Lake Hills	dry	sl. rough	1370	85	80	93	81	64	69	206
2/3/81		dry	smooth	117	42	35	29	37	34	30	49
3/24/81		wet	smooth	225	46	37	17	29	23	23	122
7/24/81		dry	sl. rough	171	77	80	71	61	67	66	39
1/20/82		wet	sl. rough	1080	48	51	50	60	39	46	562
1/29/82		wet	smooth	297	74	64	49	57	43	47	77
2/4/82		wet	smooth	551	54	34	34	34	23	25	253

particle sizes. Almost all of the larger material was removed with the first vacuum pass, but smaller fractions of the finer material were removed. This difference in sample recovery by particle size was much more pronounced for damp streets than for the dry streets. It typically required two dry vacuumings and one wet to remove more than 90 percent of the different pollutants from the street surface.

Table E-1 also shows the total solids remaining on the street surface after a single dry vacuuming. These remaining loading values correspond to the particulate material that was trapped within the texture of the street surface. It is obvious that the sampling equipment was more effective than the rains and the street cleaning equipment in removing street surface particulates: at no time was the street surface loading undetectable. The lowest measured street surface loadings during this study was about 100 lbs/curb-mile (28 g/curb-meter). The highest observed street surface loading values were about 1500 lbs/curb-mile (430 g/curb-meter), with typical values around 400 lbs/curb-mile (110 g/curb-meter). These values represent the particulate loadings above the non-recoverable loadings. The unrecovered base particulate loading values shown in Table E-1 can be considered as a measuring datum that changes for different conditions.

These tests were extremely time consuming to conduct; only 14 tests were conducted throughout the program period, representing different conditions. The most important conditions affecting sampling efficiency were assumed to be street moisture and texture conditions. These two factors were considered in a two-level factorial analysis. The 14 data points corresponding to remaining total solid loadings on the street were separated into four categories corresponding to the four possible street moisture/texture conditions. A factorial analysis was then conducted to determine if either or both of these factors were important in determining the residual loading value. The calculations showed that the street texture was the most important factor, with street moisture being of less importance. The calculated loading values for smooth textured streets were about 135 lbs/curb-mile (38 g/curb-meter) while it was about twice this value (270 lbs/curb-mile, or 76 g/curb-meter) for rough-textured streets. The variations for the loadings due to street textures depended on the texture conditions. The variation was quite small for the smooth streets (about 65 lbs/curb-mile, or 18 g/curb-meter) while it was much greater for the rough-textured streets (about 200 lbs/curb-mile, or 580 g/curb-meter). These variations were large because the sampling effectiveness studies were conducted for a variety of separate test and street conditions. These were all small area tests and do not consider average conditions which actually occurred in the large-scale sampling programs.

It is expected that the datum levels slowly fluctuated when averaged throughout the whole study basins. The expected fluctuation of the datum is estimated to be about ten or 15 percent in each sampling period, well within the 25 percent sampling error based upon the variations in observed loadings. Most of the analyses considered relative changes in street surface loadings (comparing the initial to residual loads for street cleaning and rainfall events and the change in street surface loading values with time).

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The loading values measured during this study are considered reasonable when compared with the loadings observed at other locations, as described in Section 7. Because the major variation was associated with the constant street textures, sampling efficiency corrections were not necessary. If there was a large fluctuation in sampling effectiveness associated with season, then it may have been worthwhile to correct the street surface loading values to absolute conditions. However, that would have required many more sampling effectiveness tests. Again, the datum variation was less than the sampling errors associated with the number of subsamples obtained. Therefore, the sampling procedures were quite appropriate when considered with the other errors in the sampling program. The selected sampling procedures are sensitive to variations in loadings over large test areas which are much larger than the residual loading variations.

Equipment Description

A pick-up truck was used to carry the equipment components, consisting of a generator, tools, fire extinguisher, vacuum hose and wand, and two wet-dry vacuum units during sample collection. The truck had warning lights, including a roof-top flasher unit. It operated with its headlights and warning lights on during the entire period of sample collection. The sampler and hose tender both wore orange, high visibility vests. Both the truck and the street cleaner used to clean the test areas were equipped with radios (city FM radios), so that the sampling team could contact the street cleaner operator when necessary.

Two industrial vacuum cleaners (2-hp, or 1.5 kilowatts, each) with one secondary filter and a primary dacron filter bag were used. The vacuum units were heavy duty and made of stainless steel to reduce contamination of the samples. The two 2-hp (1.5 kilowatt) vacuums were used together by using a wye connector at the end of the hose. This combination extended the useful length of the 1.5 inch (38 mm) hose to 35 feet (11 meters) and increased the suction. A wand and a gulper attachment were also used. The generator used to power the vacuum units was of sufficient power (3600 watt, heavy duty, low-RPM) to handle the electrical current load drawn by the vacuum units. The gulper attached to the end of the wand, was triangular in shape and about six inches (150 mm) across.

Sampling Procedure

Because the street surfaces were more likely to be dry during daylight hours (necessary for good sample collection), collection did not begin before sunrise nor continue after sunset, unless additional personnel were available for traffic control. Two people were required for sampling at all times: one acting as the sampler, the other acting as the vacuum hose tender and traffic controller. This lessened individual responsibility and enabled both persons to be more aware of traffic conditions.

Before each day of sampling, the equipment was checked to make sure that the generator's oil and gasoline levels were adequate, and that the vacuum

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hose, wand and gulper were in good condition. A check was also made to ensure that the vacuum units were clean, the electrical cords were securely attached to the generator and the trailer lights and warning lights were operable. The generator required about three to five minutes to warm up before the vacuum units were turned on one at a time (about five to ten seconds apart to prevent overloading the generator).

As part of the general sampling procedure, each subsample included all of the street surface material that would be removed during a severe rain (including loose materials and caked-on mud in the gutter and street areas). The location of the subsample strip was carefully selected to ensure that it had no unusual loading conditions (e.g., a subsample was not collected through the middle of a pile of leaves; rather it was collected where the leaves were lying on the street in their normal distribution pattern). When possible, wet areas were avoided. If a sample was wet and the particles caked around the intake nozzle, the caked mud from the gulper was carefully scraped into the vacuum hose while the vacuum units were running.

Subsamples were collected in a narrow strip about six inches (150 mm) wide (the width of the gulper) from one side of the street to the other (curb-to-curb). In heavily traveled streets where traffic was a problem, some subsamples consisted of two separate half-street strips (curb-to-crown). Traffic was not stopped for subsample collection; the operators waited for a suitable traffic break. On wide or busy roadways, a subsample was often collected from two strips several feet (one meter) apart, halfway into the street. On busy roadways with no parking and good street surfaces, most particulates were found within a few feet (one meter) of the curb, and a good subsample could be collected by vacuuming two adjacent strips from the curb as far into the traffic lanes as possible. A sufficient break in traffic allowed a subsample to be collected halfway across the street.

Subsamples taken in areas of heavy parking were collected between vehicles along the curb, as necessary. The sampling line across the street did not have to be a continuous line if a parked car blocked the most obvious and easiest subsample strip. A subsample could be collected in shorter strips, provided the combined length of the strip was representative of different distances from the curb. Again, in all instances, each subsample was representative of the overall curb-to-curb loading condition.

When sampling, the leading edge of the gulper was slightly elevated above the street surface (1/8 to 1/4 inch, or 3 to 6 mm) to permit an adequate air flow and to collect pebbles and large particles. The gulper was lifted further to accept larger material as necessary. If necessary, leaves in the subsample strip were manually removed and placed in the sample storage container to prevent the hose from clogging. If a noticeable decrease in sampling efficiency was observed, the vacuum hoses were cleaned immediately by disconnecting the hose lengths, cleaning out the connectors (placing the debris into the sample storage container) and reversing the air flows in the hoses (blowing them out by connecting the hose to the vacuum exhaust and directing the dislodged debris into the vacuum inlet). The use of the translucent plastic vacuum hose allowed the operators to assess the amount of material clogged in the hose. If any mud was caked on the street surface in the subsample strip, the sampler loosened it by scraping a shoe along the subsample path (being certain that street construction material was not removed from the subsample path unless it was very loose). Scraping caked-on mud was done after an initial vacuum pass. After scraping was completed, the strip was revacuumed. A rough street surface was sampled most easily by pulling (not pushing) the wand and gulper toward the curb. Smooth and busy streets were usually sampled with a pushing action.

An important aspect of the sample collection was the speed at which the gulper was moved across the street. A very rapid movement significantly decreased the amount of material collected; too slow a movement required more time than was necessary. The correct movement rate depended on the roughness of the street and the amount of material on it. When sampling a street that had a heavy loading of particulates, or a rough surface, the wand was pulled at a velocity of less than one foot (0.3 meter) per second. In areas of lower loading and smoother streets, the wand was pushed at a velocity of two to three feet (0.6 to 0.9 meter) per second. The best indication of the correct collection speed was given by visually examining how well the street was being cleaned in the sampling strip and by listening to the collected material rattle up the wand and through the vacuum hose. The objective was to remove everything that was lying on the street that could be removed by a significant rainstorm. It was quite common to leave a visually cleaner strip on the street where the subsample was collected, even on streets that appeared to be clean.

In all cases of subsample collection, the sampler and hose tender continuously watched for oncoming vehicles. While working near the curb out of the traffic lane (typically an area of high loadings), the sampler visually monitored the performance of the vacuum sampler. In the street, he constantly watched traffic and monitored the collection process by listening to particles moving up the wand. A large break in traffic was required to collect dust and dirt from street cracks in the traffic lanes, because the sampler had to watch the gulper to make sure that all of the loose material in the cracks was removed.

The hose tender also always watched for traffic. In addition, he played out hose to the sampler as needed and kept the hose as straight as possible to prevent kinking. If a kink developed, sampling stopped until the hose tender straightened the hose.

When moving from one subsample location to another, the hose, wand and gulper were securely placed in the truck. The hose was placed away from the generator's hot muffler to prevent hose damage. The generator and vacuum units were left on and in the truck during the entire subsample collection period. This helped dry damp samples and reduced the strain on the vacuum and generator motors.

The length of time it took to collect the subsample varied with the number of subsamples and the test area. For the first phase of this study, the test areas required the following sampling effort:

TEST AREA	NO. OF SAMPLES	SAMPLING PERIOD
Surrey Downs - main basin fair-good asphalt, concrete gutters	16	0.5-1.0 hr.
Surrey Downs - 108th Ave. poor asphalt, no curbs	9	0.5 hr.
Surrey Downs - Westwood Homes Rd. good asphalt	12	0.5 hr.
Lake Hills fair-good asphalt	60	2-2.5 hr.

In the Surrey Downs main basin and on 108th Avenue, two curb-to-curb passes were made at each of the 16 sampling locations due to relatively low particulate loadings. In Lake Hills, subsamples were collected by a half pass (from the crown to the curb of the street). These modifications were necessary because several hundred grams of sample material were needed for the laboratory tests and too much sample is difficult to sieve. An after street cleaning subsample was not collected from exactly the same location as the before street cleaning subsample (taken from the same general area), but at least a few feet (one meter) apart.

A field-data record sheet kept for each sample contained:

- o Subsample numbers
- o Dates and time of the collection period
- o Any unusual conditions or sampling techniques.

A tally of subsample locations where the street cleaner was unable to operate next to the curb because of parked vehicles was kept, allowing analysis of the effect of parked cars on street cleaning performance.

Sample Transfer

After all subsamples for a test area were collected, the hose and wye connection were cleaned if necessary. The translucent hose allowed visual inspection for trapped material or excessive dirt in the hose.

The vacuums were either emptied at the last station or at a more convenient location. To empty the vacuums, the top motor units were removed and placed out of the way of traffic. The vacuum units were then disconnected and lifted out of the truck. The secondary, coarse vacuum filters were removed from the vacuum can and were carefully brushed with a small whisk broom into a plastic bucket. The primary dacron filter bags were kept in the vacuum can and shaken carefully to knock off most of the filtered material. The hose inlet was blocked with a leg or knee, and the primary filter bag was held onto the vacuum drum with arms and chest. The dust inside the can was allowed to settle for a few minutes, then the primary filter was removed and brushed carefully into the sample can with the whisk broom. Any dirt from the

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top part of the bag where it was bent over the top of the vacuum was also carefully removed and placed into the sample jar.

After the filters were removed and cleaned, one person picked up the vacuum can and poured it into the bucket, while the other person carefully brushed the inside of the vacuum can with a soft three- to four-inch (76 to 102 mm) paint brush to remove the collected sample. In order to prevent excessive dust losses, the emptying and brushing was done in areas protected from the wind. To prevent inhaling the sample dust, both the sampler and the hose tender wore mouth and nose dust filters while removing the samples from the vacuums. Samples were then transferred to one quart (0.9 liter) Mason jars for storage until analysis.

To reassemble the vacuum cans, the primary dacron filter bag was inserted into the top of the vacuum can with the filters' elastic edge bent over the top of the can. The secondary, coarse filter was placed into the can and reassembled on the truck. The motor heads were then carefully replaced on the vacuum cans, making sure that the filters were on correctly and the extra electrical cord was wrapped around the handles of the vacuum units. The vacuum hoses and wand were attached so that the unit was ready for the next sample collection.

The storage jars were labeled with the date, the test area's name, and an indication of whether the sample was taken before or after the street cleaning test or if it was an accumulation (or other type of) sample. Finally, the sample jars were transported to the laboratory for logging-in and analysis or storage.

Variability Test Procedures

Variability tests were conducted seasonally in each test area to determine how many subsample locations were necessary to collect a suitable representative sample. About 50 individual locations were sampled in each test basin during each of four variability test phases. The first test phase data were eliminated because the samples were collected using the initial sampling equipment that was later replaced; and because the samples were biased by sand applications on the roads due to an unusual snowstorm. The individual samples were weighed and their variabilities were calculated. The formula used to determine the number of subsamples needed is as follows:

$$N = 4s^2/L^2$$

where:

N = number of subsamples needed
s = standard deviation
L = allowable error

This formula was used to balance the sampling effort for the different test phases and for each test basin. In most cases, an allowable error of about 25

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percent of the sample mean value resulted in a reasonable sampling effort. The samples had to be obtained in a relatively short period of time (preferably within about two hours). This allowed samples to be collected immediately before and after each street cleaning operation. Because of the frequent rains in the Bellevue area, a short sampling time was also needed to prevent samples from being rejected frequently due to rain interferences.

These samples also enabled various portions of the watershed to be compared with each other. Bellevue street cleaning equipment could not operate on 108th Avenue and Westwood Homes Road in the Surrey Downs basin because of streets and gutters in poor condition or private ownership. Therefore, the Surrey Downs basin had to be subdivided into these three subsections, each requiring individual sampling. No major loading variations were found in the Lake Hills area.

A single vacuum was used to collect the experimental design, with each sample consisting of one curb-to-curb pass. The samples were then emptied from the vacuum canister into a bucket lined with a plastic bag. The bag was then wired shut, labelled and stored for later weighing in the laboratory. Information describing each subsample location was also obtained. This information included the sampling date and location, the presence and type of gutters, the street condition, slope, and width, the parking density, and the traffic density and speed. Information concerning the adjacent area was also obtained. This included the landscaping practices adjacent to the street, the presence of leaves on the street, and the adjacent land-use (socio-economic condition, single- or multiple-residential family units, commercial areas, vacant lots, schools, churches, or other areas). Each information sheet also included the individual sample loadings expressed in lbs/curb-mile. This information is discussed in Section 7.

DRIVING LANE TEST

Periodic street surface particulate samples were collected from only the driving lanes immediately after a collection of a regular full street-width sample. These samples were collected from the center lane of the street to the edge of the parking lane. These samples were processed in a similar manner as the regular street surface particulate samples but no chemical analyses were performed. These samples, which were collected several times during the second project year, helped determine the presence of street surface particulates available for street cleaning. The data can also be used to indicate the importance of parked cars and necessary parking controls for street cleaning improvements.

ACROSS THE STREET TESTS

Several special tests were conducted to determine the redistribution of street surface particulates across the street during street cleaning operations. Two adjacent sections of street, about ten feet (3 meters) along the curb, were selected for each test. Several strips parallel to the curb were marked in each section. Each strip in one section (the furthest in the direction of travel) was individually sampled prior to street cleaning. After the sampling was completed, the street cleaner made a single pass over both of the sections. The street cleaner started about one block up the street to eliminate startup effects and broom streakings. After the street dried off, the strips in the other section were then individually sampled. The corresponding sample weights in strips in both sections were compared to determine how much of the material was removed by the street cleaner or pushed out into the middle of the street and not removed. The samples were analyzed in a manner similar to the other street surface particulate samples, but no chemical analyses were conducted.

CATCHBASIN INVENTORY AND SAMPLING

All catchbasins, manholes, and inlets were inventoried by the Bellevue survey crew at the beginning of the project. Recorded information included catchbasin number, elevations (top of grate, bottom of catchment, and all pipe inverts), size, type, and length of each pipe. The Survey Division then mapped the drainage systems.

The first sediment inventory was conducted during December, 1979. At that time, the catchbasin dimensions were measured. The sediment depth was measured by pushing a tape measure or a measuring stick into the sediment until it hit the bottom of the catchbasin. A second sediment inventory during July and August, 1980, was also conducted. The procedure was changed when it was discovered that a rock may be struck on occasion instead of the bottom of the catchbasin, resulting in a false depth value. The final measurements were made from the top of the grate to the top of the sediment; a simple measurement that did not require lifting the grate. The catchbasin depth was known and the sediment depth was then calculated. Pipe sediment and standing water were also observed through the grate.

The sediment inventory was conducted about twice yearly during the project. Spot checks were also made in about ten percent of the catchbasins after several significant rains.

Sediment samples were also taken during the inventories. Five catchbasins and five pipe sediment samples were taken in each area during each sampling. Samples were originally obtained using a scooper, pouring excess water off before transferring to a sample container. Finally they were obtained with a coring device. Excess water was pumped out of the top of the corer before pulling the sample out. Usually three to five cores were taken in various spots in each catchbasin sampled in order to obtain enough sample. Pipe sediment samples were also scooped or scraped out of the pipe. Samples were weighed, dried, and sieved into size fractions. Some of the sample fractions were then combined into three samples for chemical analyses: <63 microns, 63-500 microns, >500 microns.

Ten sediment and ten supernatant samples were taken from each study area in February, 1980, and another five sediment samples were taken from each area in March, 1980, for chemical analysis (Total Solids, Chemical Oxygen Demand, Kjeldahl Nitrogen, Total Phosphorus, Lead, and Zinc).

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APPENDIX F
STREET DIRT SAMPLE PREPARATION AND DATA HANDLING

INTRODUCTION

This appendix summarizes the street surface particulate handling procedures used in Bellevue. These procedures were used after the samples were collected and before they are sent to the laboratory for analysis. This appendix also briefly describes the preliminary calculations and organization of the data needed before detailed data analysis. Recommended procedures for obtaining street surface particulate samples were described in Appendix E. Originally, these techniques were described in the report "Demonstration of Nonpoint Pollution Abatement Through Improved Street Cleaning Practices" (Pitt, EPA-600-2/79-161, U.S. Environmental Protection Agency, August 1979). Modifications of these techniques for the Bellevue Urban Runoff project have been discussed and approved by EPA project officers during field visits. The scope of this appendix is limited to the discussion of the day to day sample handling practices necessary to prepare the samples for subsequent laboratory analysis.

SAMPLE DESCRIPTION

Specific information collection techniques were employed for consistency and proven ease of data collection. Table F-1 is an example of a checksheet that can be used during the experimental design of street surface sampling activities. These activities require about 50 to 100 individual street surface sampling strips to be cleaned. All of the samples are then individually weighed. This results in an indication of street surface particulate loading variations over the study area. The characteristics on this checksheet are noted for each individual sample and are stored for future reference. This information is extremely useful in determining the causes for extreme loading values observed at any specific sampling location. The information in Table F-1 can then be summarized on a percentage basis to describe the specific test area characteristics. The most important test area characteristics include the street surface and curb-street interface conditions.

INFORMATION TO BE NOTED DURING STREET CLEANING OPERATIONS AND SAMPLE COLLECTION

It is important that the street cleaning equipment operator fill out a simple form every time the test areas are cleaned. Table F-2 is an example of a form that is used to confirm street cleaning activities and to note unusual

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Table F-1. SAMPLE AREA DESCRIPTION

STUDY AREA: Middle Test Area

LOCATION: 2234 Kipling Dr.

DATE: 9/25/82

PHOTO NUMBER: 27

SAMPLE INFORMATION:
I.D. Number: 7
Weight* (grams): 82.4
Loading* (lb/curb-mile): 958

GUTTERS:
Number: 1, [✓ 2] 3, 4
Type: concrete, [✓ asphalt]
Shape: [✓ straight], rolled
Median strip: yes, [✓ no]

STREET:
Material: concrete, [✓ asphalt], other:
Condition: poor, [✓ fair], good
Width: < 20 ft, [✓ 20 to 40] ft, > 40 ft

CURB/STREET INTERFACE:
Condition: poor, [✓ fair] good

CURB TYPE (at sampling location): rolled, [✓ straight]
Type: paved driveway, dirt driveway, corner, [✓ regular] curb face, other**

TRAFFIC:
Density: [✓ light], moderate, heavy
Average Speed: < 25 mph, [✓ 25 to 40 mph], > 40 mph

PARKING:
Density: none, [✓ light], moderate, heavy

SURROUNDING AREA:
Land use type:
low income/old/single family
[✓ medium income/old/single family]
medium income/new/single family
multiple family
commercial
vacant land
schools
other**

Landscaping vegetation: deciduous, [✓ evergreen], other:
Vegetation density: sparse, [✓ moderate], dense
Leaves on street: sparse, [✓ moderate], dense
Topography: [✓ flat], moderate, steep

AREA ADJACENT TO CURB AND SIDEWALK:
Surface type: [✓ grass]
paved
unimproved (dirt, rocks)
other:

COMMENTS: to be resurfaced soon

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*This information is to be recorded after laboratory analyses have been conducted.

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Table F-2. INFORMATION FOR STREET CLEANING TESTS

STUDY AREA: Middle test area

DATE: 7/6/82

EQUIPMENT:
Unit number or name: Mobil #367
Adjusted as specified
for this test: [✓ yes], no, other*

TIME:
Start of test: 0830
End of test: 1020

HOPPER CONTENT:
Empty before test? [✓ yes] no, other*
Estimated volume or weight
after test: 42 [✓ cu. yds] or pounds

COMMENTS:**
dry streets, but windy

OPERATORS SIGNATURE: TJB Bloner

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*Explain "other" under COMMENTS

**Note any unusual conditions (e.g., wind, rain, construction, street maintenance, spills)

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conditions. The important parameters are the dates and times of street cleaning and an indication of weather conditions that may adversely affect the street cleaning operation.

Similarly, the street surface particulate sampling crew must also fill out a simple form for each sample collected. Table F-3 is an example form which notes the important information necessary to resolve future likely disputes and inconsistencies with times, dates, weights and sample numbers. The time at the start of the collection and at the end of the collection is noted. Subsamples collected where the street cleaner was unable to operate next to the curb were noted on the sampler log. This results in an indication of the parked car densities in the study area.

When the samples are transferred from the vacuum collection equipment to the storage canisters, the date and test area is written on the can, along with the type of sample. When the sample is returned to the laboratory, each sample is given an identification number which is also written on the can and on the sample checklist.

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PHYSICAL ANALYSIS

The sample description information written on the test area sample checklist at the laboratory is also noted on a sample inventory sheet. Table F-4 is an example of this sheet and shows the chronological inventorying of each sample immediately after collection. The samples are then prepared for particle size and chemical analysis.

Most street surface samples are quite dry and do not experience chemical or biological degradation, over short storage periods, of the constituents typically monitored. In many cases, street surface particulates can lie exposed on the road surface for up to three months before rains wash them into the receiving waters. During this time, they may be intermittently moistened and subjected to a wide range of temperatures. Although the laboratory storage times should be kept to a minimum, they are likely to be several months long due to the necessity of compositing samples over testing time periods, as described later in this section.

For physical analysis, the samples are transferred from their storage containers to well-labelled drying pans. These pans are then placed in a low temperature drying oven for several hours at 70-75 degrees F (21-24 degrees C). Again, this heating does not typically affect the chemical characteristics of the samples, except for the more volatile phosphorus and mercury compounds that may be analyzed in street surface particulates. If, through special tests, appreciable quantities of certain constituents of importance are lost during sample drying, then subsampling of the complete sample mixture for analysis for those specific compounds may be necessary. However, because of the heterogeneity of the street surface particulates, obtaining a representative subsample from the whole sample is extremely difficult and can introduce significant errors. Table F-5 is an example of the data form used when drying the samples. The gross and net weights of the samples are noted and the percent moisture is calculated. Again, this

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Table F-3. STREET SAMPLING CHECKLIST (for use during field program)

SAMPLE:
I.D. number: A-37
Type: before street cleaned, after street cleaned, [✓ accumulation]

STUDY AREA: Middle test area

DATE: 313182

TIME:
At start of sampling: 0930
At end of sampling: 1340

SUB-SAMPLE STRIP TALLY:
~~1~~ S
~~2~~
~~3~~
~~4~~ S
~~5~~
~~6~~ S
~~7~~ S
~~8~~
~~9~~
~~10~~
~~11~~ S
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49
50
51
52

Note : Check off the numbers as the strip samples are collected (each strip is assumed to be located between the curb and the center line; i.e., half strips). Flag locations where parked cars interfered.

PARKING INTERFERENCE:
Total number of strip samples collected: 36
Strips where parked cars interfered: 14
Parked car density (percent): 39%

SAMPLE WEIGHTS:*
Gross wet weight (grams): 1256
Tare weight (grams): 286
Net wet weight (grams): 920

COMMENTS: Sunny & dry

SAMPLING TEAM MEMBERS: Hal Hone, KD Winter

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*This information is to be recorded after laboratory analyses have been conducted.

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Table F-4.**SAMPLE INVENTORY SHEET**

SAMPLE ID NUMBER	DATE COLLECTED	TIME COLLECTED	STUDY AREA	NET WET WEIGHT OF UN-SEIVED SAMPLE (grams)	COMMENTS
S-19	3/2/80	0830 → 0930	middle	990g.	1/2 6 trips
S-20	3/6	0800 → 0900	middle	970	"
A-91	3/6	0930 → 1000	lower	340	"
S-21	3/12	0800 → 0900	middle	1175	"
S-22	3/14	0830 → 0930	middle	1280	"
S-42	3/14	1000 → 1030	upper	1175	"

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Table F-5. **MOISTURE CONTENT DATA SHEET**

SAMPLE ID NUMBER	DRYING PAN NUMBER	TARE WEIGHT (grams) a	GROSS WET WEIGHT (grams) b	GROSS DRY WEIGHT (grams) c	NET WET WEIGHT (grams) d	NET DRY WEIGHT (grams) e	MOISTURE CONTENT (percent) f
A-28	4	47	603	596	556	549	1
A-29	5	47	570	563	523	516	1
A-30	6	47	330	327	283	280	1
A-31	7	47	831	825	784	778	1
A-32	8	47	829	820	782	773	1
A-33	9	654	1188	1184	534	530	1
S-9	10	47	1029	1014	982	967	2
S-10	11	651	1018	1012	367	361	2

Note: $d = b - a$

$e = c - a$

$$f = \frac{d - e}{d} \times 100\%$$

complete information must be noted for each sample in order to resolve problems that may later occur due to misplacing or mislabelling samples.

After adequate drying, the samples are passed through a set of mechanical, stainless steel sieves for size separation. The sieve sizes being used are 63, 125, 250, 500, 1,000, 2,000 microns, and 1/4 inch (6,370 microns). If the sample contains large amounts of coarse material it may be necessary to pass the sample through a 1/4 inch (6,370 micron) coarse sieve made of hardware cloth attached to a wooden (25 by 100 mm) frame, about two feet (600 mm) square. Samples less than 63 microns are retained on the pan on the bottom of the sieve stack. Table F-6 is a worksheet showing the calculations for this sieve analysis. The gross weight of each sieve plus associated retained sample is noted along with the tare weight of the sieve. A top loading precision balance is required for the weighing. The net dry weight of this sample is then shown and totaled. The percentage of sample in each size fraction is also calculated and presented on this sheet along with the pounds per curb-mile (or g/curb-meter) loading factor (the calculation for this will be described later). It is important to note that detailed sample descriptions are presented on this sheet. Specifically, the sample number, date and test area are written in along with the total net raw sample weight as shown on the initial sample inventory sheet. This weight is then compared with the total net weight for the sample. The net raw wet weight is not as precise as the total of the sieved dry weights (because of the sample drying and different scales typically used) but there should usually be less than a five percent difference. If a large discrepancy exists between these two weight values, then the sample should be rechecked by observing the notes from the sample drying, inventory and test area checksheet along with any other information available. In addition, the percent sample should add up close to 100 percent.

CALCULATION OF STREET LOADING VALUES

The calculation to convert the quantity of sample expressed in grams to a representative street loading value expressed in pounds per curb-mile (or g/curb-meter) varies, depending upon the sampling technique and equipment.

The width cleaned with each subsample strip is slightly wider than the gulper width, because of material being drawn into the sides of the gulper. The actual cleaning width can be measured directly on the street when sampling a moderately dirty street surface.

A variety of subsampling procedures may be necessary depending upon special circumstances. At least 200 grams of sample are necessary for the mechanical sieving analyses. Therefore, if the streets to be sampled are very clean, then multiple adjacent subsampling strips may be necessary. In other circumstances, traffic hazards may prohibit sampling from curb to curb, and curb to crown subsampling strips may be necessary. Table F-7 shows the equivalent number of full strips for these various subsampling schemes, along with the number of subsampling full width strips necessary to make one

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Table F-6. PARTICLE SIZE ANALYSIS DATA SHEET

STUDY AREA: Middle

DATE SAMPLED: 3/16/80

DATE ANALYZED: 3/30/80

SAMPLE
ID number: A-44
Net raw weight (grams): 495

SIEVE SIZE (microns)	TARE WEIGHT (grams) a	GROSS DRY WEIGHT (grams) b	NET DRY WEIGHT (grams) c	AMOUNT OF SAMPLE REMAINING ON SIEVE (percent of total net dry weight) d	PARTICLE* LOADING DRY (lbs per curb mile)	COMMENTS
> 6370	0	37	37	7.7	24.1	mostly leaves
2000 → 6370	482	572	90	18.8	58.5	
1000 → 2000	449	575	126	26.3	81.9	
500 → 1000	434	485	51	10.6	33.1	
250 → 500	403	504	101	21.1	65.7	
125 → 250	379	429	50	10.4	32.5	
63 → 125	375	395	20	4.2	13.0	
<63	371	375	4	0.8	2.6	
TOTAL	—	—	479	99.7	311	

*See equation 1 to convert net dry weight per sample (grams/sample) to street loading. (lbs/curb mile)

$c = b - a$

$d = \frac{c}{\Sigma c} \times 100\%$

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Table F-7. **EQUIVALENT NUMBER OF FULL STRIPS FOR VARIOUS SUB-SAMPLING SCHEMES**

SUBSAMPLING STRIPS	EQUIVALENT NUMBER OF FULL (CURB-TO-CURB STRIPS)
12 half-strips 3 double-strips	6 full-strips
10 half-strips	5 full-strips
14 half-strips	7 full-strips
16 half-strips 4 double-strips	8 full-strips
18 half-strips	9 full-strips
20 half-strips 5 double-strips	10 full-strips
30 half-strips	15 full-strips
40 half-strips 10 double-strips	20 full-strips
50 half-strips	25 full-strips

curb-mile (1600 curb-meters).

SUMMARIES OF RAIN EVENTS

It is very important to keep careful records of the precipitation events occurring during the project period. Tables F-8 and F-9 together are an example of a complete rain record. Table F-8 summarizes the total amount of rain that has occurred on each day during the project period. Monthly totals are also shown on Table F-8. This table is used to determine the antecedent dry conditions before any sample and it also shows the variability of precipitation within storm periods. Table F-9 presents more detail for each of the storms that occurred during the sampling program. This summary also shows which storms were monitored at the runoff monitoring stations and which rains are considered significant.

A significant rain event is one that is capable of removing most (greater than 90 percent) of the street surface particulates from the street. Some of the smaller significant rains, however, may not be capable of totally moving all of the street surface particulates through the storm sewerage system and into the receiving waters. A storm of about 0.2 inch (5 mm) total (occurring over several hours and during periods of moderate to heavy traffic) can move most of the street surface particulates from the street and into the drainage system. Therefore, rains of this magnitude, or greater, are typically considered significant. If the street surface material is very coarse, caked with large quantities of debris (mud or leaves), or in very poor condition, a much greater quantity of rain may be necessary. In addition, if the rains occur at nighttime, or at other periods of very low traffic activity, then more rain would be necessary to remove most of the street surface particulates. Traffic volume is an important consideration because of the ability of the vehicles to loosen particulates from the road surface. The rain then only has to transport material to the curb and along the curb to the storm drainage inlet. The smaller rains, however, are probably not sufficient to move the material through the storm drainage system into the receiving water. Therefore, this particulate material would accumulate in the sewerage system to be flushed out by later larger storms. Storms of about 0.5 inch (13 mm) total, occurring within several hours, are usually capable of removing all of the street surface material and moving it all the way through the storm sewerage system and into the receiving water, irrespective of traffic conditions. However, larger rains can result in significant erosion yields from the surrounding land areas. This erosion material is washed onto the street surfaces and into the storm sewerage system. In some cases, the street surface loadings after storms can be greater than the loadings before storms, because of this erosion. In areas of the semi-arid west, rains of about one inch (25 mm) or more, can create much greater erosion yields for many constituents in urban areas than the street surface runoff yields. However, in areas of the Midwest, much greater rain quantities are necessary before significant erosion yields contribute to the urban runoff flow.

Table F-9 also shows the time of the beginning and the ending of the rain event. These values are compared to the times of beginning and ending of

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Table F-8. DAILY RAIN RECORD SUMMARY

WATER YEAR: 1980-1981 RAIN GAUGE: Proctor School

DAY	MONTH											
	OCT 1980	NOV 1980	DEC 1980	JAN 1981	FEB 1981	MAR 1981	APR 1981	MAY 1981	JUN 1981	JUL 1981	AUG 1981	SEPT 1981
1				0.01								
2		0.01		0.01		0.33						
3		0.56				0.05						
4		0.01				0.28	0.30					
5		0.02		0.01		0.32	0.79	0.02				
6						0.29		0.05		0.01		
7								0.04				
8		0.03		0.05				0.03				0.21
9		0.02		0.38								
10				0.42								
11				1.22		0.01						
12				0.24								
13				1.35								
14				0.01	0.66	0.03						
15		0.78		0.20	0.64	0.01		0.01				
16		0.05		0.11	1.13							
17				0.14	0.24							
18	0.15				0.68						0.38	
19	0.84	0.41	0.44		1.31				0.01			
20	0.02		0.13		0.89		0.11					
21					0.38	0.01	0.09					
22		0.22					0.19					
23		0.10	1.59									0.01
24			1.46		0.01							
25	1.68		0.47			0.19						
26	0.01											
27					0.73							
28					0.01	0.01						
29					0.01							
30	0.03		0.25									
31	0.01		0.37									
TOTAL	2.74	2.21	4.71	4.15	6.69	1.53	1.45	0.15	0.01	0.01	0.38	0.22

Annual Total : 24.25

Note: Tabulated values are rainfall amounts in inches

Table F-9. SUMMARY OF RAIN EVENTS DURING FIELD ACTIVITIES ***

DATE RAIN BEGAN	TIME RAIN BEGAN	DATE RAIN ENDED	TIME RAIN ENDED	DURATION (hours)	TOTAL PRECIP-ITATION (inches)	AVERAGE INTENSITY (inches/hour)	PEAK INTENSITY (inches/hour)	WAS THE EVENT MONITORED* (yes/no)	WAS THE EVENT SIGNIFI-CANT** (yes/no)
2/17/78	0530	12/17	1800	12.5	0.39	0.03	0.14	Y	Y
12/18	0815	12/18	2400	15.8	0.05	0.003	0.03	N	N
12/19	0130	12/19	0145	0.3	0.01	0.01	0.01	N	N
1/7/79	0830	1/7	2315	14.8	0.34	0.02	0.05	Y	Y
1/8	0945	1/8	1545	6.0	1.24	0.21	0.40	N	Y

*"Monitored" requires all rain and runoff measurements between adjacent street surface samples. The time since the rain ended and the "after" street surface sample should be less than one day, in most cases.

**"Significant" as defined in the text.

***Each rain "event" is separated by at least 6 hours of no precipitation. Several adjacent rain events are usually grouped together to make a complete monitored "data set". See the above definition of the "monitored" criteria that defines a complete data set.

runoff to obtain lag values and are necessary in order to calculate the accumulation periods for street surface samples taken near a rain event.

PREPARATION OF LOADING SUMMARIES

Simple summary forms are necessary to display the street surface loading results for accumulation and test samples. Tables F-10 and F-11 are examples of completed summary forms. Table F-10 shows the size distribution and loadings for a street surface accumulation sample. Information shown on this table include a complete sample description along with the climatic conditions during the time of sampling and for the last rain event. The median particle size is also shown on this table. Table F-11 is similar, but a pair of street cleaning test samples are presented side by side with the loading difference calculated and expressed as the street cleaning effectiveness. The amount removed, expressed in pounds per curb-mile (or g/curb-meter) is stressed, but the percentage removed of the before loading is also presented as a normalized value. The times of street cleaning and sampling are also shown on these forms in order to calculate accumulation periods and to confirm the test scheduling.

SAMPLE COMPOSITING FOR CHEMICAL ANALYSIS

Before any additional preliminary calculations of street surface particulate characteristics are possible, chemical laboratory analyses must also be performed. The most cost effective procedure is to physically composite similar samples before chemical analysis. After mechanical sieving, the different particle sizes are stored in separate plastic bags or bottles as appropriate and replaced in their original storage containers. The compositing involves combining equal quantities (typically five or ten grams) of each size fraction of all samples collected in a single study area over a short period of time. Equal quantities from each bag from the same particle size, but different samples, are combined to obtain a composite sample representing a single particle size for all samples in the compositing time period and test area. Leftover samples are replaced in the cans and saved.

Equal sample quantities must be composited because we are interested in obtaining a time averaged chemical analysis of the material. The time phases for compositing should be based upon major seasonal differences and street cleaning practices conducted within the areas. Table F-12 is an example of how the time periods could be identified. This table shows six different time phases for three different study areas. The time periods range from a short two weeks for special leaf removal tests up to six weeks. A total of eight size ranges, times six time periods, times three test areas, or 144 samples, will be prepared for chemical analyses. This will result in chemical descriptions of specific particle sizes within time and area subunits. It is much more important to analyze different particle sizes for the different chemical constituents than analyzing each separate sample. The chemical concentrations vary substantially within each particle size. This variation is shown to be much greater than either seasonal or aerial variations. In addition, it is very difficult to subsample a complete sample to obtain a

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Table F-10. STREET SURFACE LOADING - RESULTS OF TESTS

STUDY AREA: Lower

SAMPLE CODE: A-104

DATE SAMPLED: 1/25/82

TIME SAMPLED: 1008 → 1108

WEATHER DURING SAMPLING: [✓ clear,] partly cloudy, cloudy
windy, moderately windy, [✓ calm]

ANTECEDENT CONDITIONS

Time since last swept (days):	9.2
Last rain:	
date:	1/17/82
precipitation (inches):	0.24
duration (hours):	6.8
intensity (inches/hour):	0.04
time since last rain (days):	8.3
Time since last significant rain (days):	8.3

TOTAL NET DRY WEIGHT: ________

SIEVE SIZE (microns)	AMOUNT OF SAMPLE REMAINING ON SIEVE		AMOUNT OF SAMPLE PASSING SIEVE (percent of total net dry weight)	PARTICLE* LOADING DRY (lbs per curb mile)
	(grams)	(percent of total net dry weight)		
>6370	22.8	1.7	100.1	15.1
2000 - 6370	132.7	9.9	98.4	89.3
1000 - 2000	255.9	19.1	88.5	173
500 - 1000	107.2	8.0	69.4	71.9
250 - 500	320.3	23.9	61.4	216
125 - 250	266.7	19.9	37.5	180
63 - 125	195.6	14.6	17.6	132
<63	40.2	3.0	3.0	26.7
TOTAL	13412	100.1	—	904

MEDIAN PARTICLE SIZE (microns): 381

***See Equation 1 for the formula to convert grams per sample to lbs per curb mile**

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Table F-11. STREET CLEANING EFFECTIVENESS

STUDY AREA: Lower

LOCATION: Slab area

DATE SAMPLED: 5/16/82

TIME SAMPLED: ____

Sample before street cleaned: 1000

Street cleaned: 1100

Sample after street cleaned: 0100

EQUIPMENT UNIT NUMBER AND/OR NAME: Mobil #580

Density of parked cars that interfered with sampling:* 39%

ANTECEDENT CONDITIONS:

Time since last swept (days): 1

Last rain:

date: 5/15/82

precipitation (inches): 0.01

duration (hours): 1

intensity (inches/hour): 0.01

time since last rain (days): 0.6

time since last significant rain (days): 20

	BEFORE STREET WAS CLEANED SAMPLE I.D. NUMBER ____			AFTER STREET WAS CLEANED SAMPLE I.D. NUMBER ____			STREET CLEANING EFFECTIVENESS		
							AMOUNT REMOVED BY STREET CLEANER		
SIEVE SIZE (microns)	AMOUNT OF SAMPLE REMAINING ON SIEVE (percent of total net dry weight)	AMOUNT OF SAMPLE PASSING SIEVE (percent of total net dry weight)	PARTICLE LOADING DRY (lbs per curb mile)	AMOUNT OF SAMPLE REMAINING ON SIEVE (percent of total net dry weight)	AMOUNT OF SAMPLE PASSING SIEVE (percent of total net dry weight)	PARTICLE LOADING DRY (lbs per curb mile)	(lbs per curb mile)	(percent of total net dry weight removed)	(percent of total net dry weight before street was cleaned)
>6370	1.2	100.1	9.3	1.2	99.2	5.8	3.5	1.2	38
2000 - 6370	7.3	98.9	54.5	8.6	98.0	40.6	13.9	4.9	26
1000 - 2000	13.5	91.6	101	11.9	89.4	55.7	45.0	16.0	45
500 - 1000	7.0	78.1	52.5	6.4	77.5	30.2	22.3	7.9	42
250 - 500	25.5	71.1	191	21.7	71.1	102	89	31.6	47
125 - 250	22.3	45.6	167	23.0	49.4	108	59	20.9	35
63 - 125	16.9	23.3	126	19.5	26.4	91.6	34	12.1	27
<63	6.4	6.4	47.6	6.9	6.9	32.5	15.1	5.4	32
TOTAL	100.1	—	749	99.2	—	466	282	100.0	38
MEDIAN PARTICLE SIZE (microns): 293				MEDIAN PARTICLE SIZE (microns) 257			MEDIAN PARTICLE SIZE (microns) 342		

Table F-12. STREET CLEANING SCHEDULE

Five Day Work Week	I.D. Code for Composite Sample	NUMBER OF STREET CLEANINGS DURING THE WEEK				
Beginning Ending		Study Location	Study Location	Study Location	Study Location	Study Location
		upper	middle	lower		
11/20→11/24 11/27→12/1	Fall#1	1 4	1 4	1 4		
12/4→1/12	Winter#1	0	0	0		
1/15→1/19 1/22→1/26 1/29→2/2	Winter#2	0 0 0	1 1 1	0 0 0		
2/5→2/9 2/12→2/16		0 0	1 0	0 0		

representative five or ten grams. The extreme heterogeneity of the samples makes this impossible without having to mill all of the sample and then remove the small quantity necessary for chemical analysis. It is much easier to select a representative five or ten grams from each particle size because of the reduced physical and chemical variation within that size range. Each composited sample is typically made up of five to 20 subsamples. These composited samples are then placed in small sample containers that are thoroughly labeled and sent to the laboratory for chemical analysis. The laboratory will have to mill the coarser samples before they are analyzed. Care should be taken to design a chemical analysis program that will key in on the most important constituents and those that are least affected by the required collection, storage and handling techniques. If special chemical analyses, such as priority pollutants, are necessary, then special samples should be collected and handled specifically for those analyses.

After the chemical analysis results are obtained from the laboratory, the chemical strength (concentrations expressed in micrograms of constituent per gram of total solids) should be summarized as shown on Table F-13. Table F-14 presents an example of the loading calculations for each of these constituents for an individual sample. Each sample collected within the time frame and for the specific test area should be identified for each composite analysis and the appropriate concentration factors used. Table F-14 also shows an example calculation to obtain the appropriate street surface loadings.

SUMMARY

This appendix describes the laboratory handling of the street dirt material before it is sent to a laboratory for chemical analysis. The preliminary data calculations and summarizing formats are also briefly described. After these stages are completed, more detailed data analyses need to be performed. These analyses include the determination of the accumulation and deposition rates of the various street surface particulate contaminants,and various measures of street cleaning effectiveness. Initial and residual street surface loadings for different street cleaning frequencies, and residual loadings as a function of initial loadings for different study area characteristics also need to be identified. In addition, as runoff monitoring will also be conducted simultaneously with street cleaning, the effects of street cleaning on runoff water quality will also be addressed in the final project report.

Table F-13. **CHEMICAL COMPOSITION OF STREET DIRT SAMPLE**

SIEVE SIZE (microns)	STRENGTH (micrograms of chemical constituent per gram of total solids)									
	Pb	Zn	COD	P	OPO_4	S	As	Cu	Cr	VS
>6370	71	68	220K	570	28	700	22	49	85	196K
2000 - 6370	92	78	120K	540	17	800	18	36	128	96K
1000 - 2000	935	145	140K	560	25	900	22	39	174	111K
500 - 1000	2050	250	130K	570	29	1200	31	43	187	104K
250 - 500	2870	295	150K	530	25	1400	22	60	163	94K
125 - 250	3790	440	140K	560	21	1700	24	110	185	92K
63 - 125	2140	500	160K	730	39	2100	19	100	24	113K
<63	3230	565	190K	900	59	2600	36	120	84	137K

Study Area: Middle
Composite Dates: winter #2 (1/15→2/16/82)
Notes: abnormally dry winter period; 1 cleaning pass per week.

Table F-14. STREET LOADING CALCULATIONS FOR CHEMICAL COMPOSITION

SIEVE SIZE (microns)	STREET LOADING (lbs per curb mile)										
	Total** solids	Pb*	Zn*	COD*	P*	OPO_4 *	S*	As*	Cu*	Cr*	VS*
>6370	478	0.0038	0.0033	11	0.027	0.0013	0.034	0.0011	0.0033	0.0041	9.4
2000 - 6370	131	0.012	0.010	16	0.071	0.0022	0.10	0.0024	0.0047	0.017	12.6
1000 - 2000	164	0.15	0.024	23	0.092	0.0041	0.15	0.0036	0.0004	0.029	18.2
500 - 1000	65.8	0.14	0.016	8.5	0.038	0.0019	0.079	0.0020	0.0028	0.012	6.8
250 - 500	180	0.52	0.053	27	0.095	0.0045	0.25	0.0040	0.011	0.029	16.9
125 - 250	137	0.52	0.060	19	0.077	0.0038	0.23	0.0037	0.015	0.025	12.6
63 - 125	106	0.30	0.053	17	0.077	0.0041	0.22	0.0020	0.011	0.010	12.0
<63	46.9	0.15	0.026	8.9	0.042	0.0028	0.012	0.0017	0.0066	0.0039	6.4
Total	878	1.8	0.25	130	0.52	0.025	1.2	0.020	0.059	0.13	95

*Calculation:
chemical Z = [total solids] x [concentration of Z] x [grams/10^6 micrograms]
(lbs/curb-mile) (lbs/curb-mile) (micrograms/gram total solids)

**For total solids amount see Table 10.

Sample Code and Type of Sample: A-B3 (accumulator)

Sample Date: 3/16/82

Test Area: Middle

Notes: abnormally dry, no street cleaning

APPENDIX G
SOURCES OF URBAN RUNOFF POLLUTANTS

There have been many studies in the past that have examined different sources of urban runoff pollutants. These references have been reviewed as part of this study and the results are summarized in this section. Significant urban runoff pollutants are defined as having a potential receiving water impact. Most of these potential problem pollutants are identified by significant concentration increases in the receiving waters or sediments, as compared to areas not affected by urban runoff. Others discussed are notoriously toxic and present in urban runoff, but their concentrations in the runoff may not create significant water problems. Sediment accumulation and bioaccumulation of these toxic pollutants, however, may be hazardous.

The important sources of these pollutants are related to various uses and processes. These include natural sources, such as rock weathering to produce soil (and solubility products of the major rock components), groundwater infiltration, volcanoes and forest fires. Automobile-related potential sources usually affect the road dust and dirt more importantly than other particulate components of the runoff sysem. The road dust and dirt quality is affected by vehicle fluid drips and spills (gasoline, oils, etc.) and gasoline combustion, along with various vehicle wear, local soil erosion and pavement wear products. Urban "agricultural" practices potentially affecting urban runoff include landscaping (vegetation litter, fertilizer and pesticide use) and animal wastes. Miscellaneous sources of urban runoff pollutants include fireworks, wildlife and possible sanitary wastewater infiltration. Precipitation and atmospheric fallout are both affected by urban runoff pollutant resuspension after initial deposition. Pesticide use in an urban area can contribute significant quantities of various toxic materials to urban runoff. Many manufacturing and industrial activities, including the combustion of fuels, also affects urban runoff quality. Therefore, it is extremely difficult to identify a small number of activities that contributes most of the significant urban runoff pollutants.

Natural weathering and erosion products of rocks contribute the majority of the hardness and iron in urban runoff pollutants. Road dust and associated automobile use activities (gasoline exhaust products) contribute most of the lead in urban runoff. Road dust, contaminated by tire wear products, contributes most of the zinc to urban runoff. In certain situations, paint chipping can also be a major source of lead in urban areas. Urban agricultural activities can be a major source of cadmium. Electroplating and ore processing activities can also contribute much cadmium. Most of the mercury released into the environment comes from the chlor-alkali and pulp and paper industries. Many pollutant sources are specific to a particular area and on-going activities. For example, iron oxides are associated with welding operations and strontium, used in the production of flares and fireworks, would probably be found on the streets in greater quantities around holidays, or at the scenes of traffic accidents. The relative contribution of each of these potential urban runoff sources is, therefore, highly variable, depending on specific site conditions and seasons.

CHEMICAL QUALITY OF ROCKS AND SOILS

Almost half of the lithosphere (the earth's crust) is oxygen and about 25 percent is silica. Approximately eight percent is aluminum and five percent is iron. Elements comprising between two percent and four percent of the lithosphere include calcium, sodium, potassium and magnesium. Because of the great abundance of these materials in the lithosphere, urban runoff contributes only a relatively small additional quantity of these elements to receiving waters. This is especially important to remember for iron, which has been analyzed in many urban runoff studies. Iron can cause detrimental effects in receiving waters, but these effects are mostly associated with its dissolved form. A reduction of the pH substantially increases abundance of dissolved iron.

Arsenic is mainly concentrated in iron and manganese oxides, shales, clays, sedimentary rocks and phosphorites. Mercury is concentrated mostly in sulfide ores, shales and clays. Lead is fairly uniformly distributed, but can be concentrated in clayey sediments and sulfide deposits. Cadmium can also be concentrated in shales, clays and phosphorites (Durum 1974).

STREET DUST AND DIRT POLLUTANT SOURCES

Most of the street surface dust and dirt material (by weight) are local soil erosion products, while some materials are contributed by motor vehicle emissions and wear. Minor contributions are made by erosion of street surfaces in good condition. The specific makeup of street surface contaminants is a function of many conditions and varies widely.

Automobile tire wear is a substantial source of zinc in urban runoff and is mostly deposited on street surfaces and nearby adjacent areas. About half of the airborne particulates lost due to tire wear settle out on the street and the remaining particulates settle within about six meters of the roadway. Exhaust particulates, fluid losses, drips, spills and mechanical wear products can all contribute lead to street dirt. Many heavy metals are important pollutants associated with automobile activity. Most of these automobile pollutants affect parking lots and street surfaces. Some materials remain on areas adjacent to streets due to wind transportation after resuspension of the particulates from the road surface, or by direct deposition after emissions.

Automobile exhaust particulates contribute many important heavy metals to street surface particulates and to urban runoff and receiving waters. The

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most notable of these heavy metals is lead. Solomon and Natusch (1977) studied automobile exhaust particulates in conjunction with a comprehensive study of lead in the Champaign-Urbana, Illinois, area. They found that the exhaust particulates existed in two distinct morphological forms. The smallest particulates were almost perfectly spherical, having diameters in the range of 0.1 to 0.5 microns. These small particles consisted almost entirely of PbBrCl at the time of emission. Because they are small, they are expected to remain airborne for considerable distances and can be deposited in the lungs when inhaled. They concluded that the small particles are formed by condensation of PbBrCl vapor onto small nucleating centers which are probably introduced into the engine with the filtered engine air.

Solomon and Natusch (1977) found that the second major form of automobile exhaust particulates were rather large, being roughly 10 to 20 microns in diameter. These typically had irregular shapes, with somewhat smooth surfaces. They found that the elemental compositions of these irregular particles was quite variable, being predominantly iron, calcium, lead, chlorine and bromine. They found that individual particles did contain aluminum, zinc, sulfur, phosphorus and some carbon, chromium, potassium, sodium, nickel and thallium. Many of these elements (bromine, carbon, chlorine, chromium, potassium, sodium, nickel, phosphorus, lead, sulfur, and thallium) are most likely condensed, or adsorbed, onto the surfaces of these larger particles during passage through the exhaust system. They believed that these large particles originate in the engine or exhaust system because of their very high iron content. They found that 50 to 70 percent of the emitted lead is associated with these large particles, which would be deposited within a few meters of the emission point onto the roadway because of their aerodynamic properties.

Solomon and Natusch (1977) also examined urban particulates near roadways and homes in urban areas. They found that soil lead concentrations were higher near the roads and houses. This indicated the capability of road dust and peeling paint to contaminate nearby soils. The lead content of the soils ranged from 130 to about 1,200 mg/kg. Koeppe (1977), as part of another element of this Champaign-Urbana lead study, found that lead was tightly bound to various soil components. However, the lead did not remain in one location, but it was transported both downward into the soil profile and to adjacent areas through both natural and man-assisted processes.

URBAN AGRICULTURAL SOURCES OF URBAN RUNOFF POLLUTANTS

Vegetative litter can be a significant pollutant component in almost all source areas. The leaf fall on streets in Bellevue is an important street surface pollutant in the fall months. Animal feces can contribute important quantities of nutrients and bacteria to the urban area, mostly affecting vacant land and landscaped areas where they tend to accumulate. Fertilizer and pesticide use is mostly associated with landscaped areas, but large amounts of pesticides are sometimes used to control plant growths in impervious areas. Fertilizer may be used in large quantities for road maintenance operations. Koeppe (1977) found that significant levels of plant-available lead may be released during decomposition of plant tissue

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containing lead. Therefore, it may be difficult to permanently immobilize the soil lead by returning polluted plant residues to the soil. These polluted plants are mostly associated with vegetative areas close to the road that have been shown to accumulate large amounts of lead in their foliage. The movement of lead during plant decomposition may be the cause for the downward movement of lead.

ATMOSPHERIC RESUSPENSION, TRANSPORTATION AND REDEPOSITION OF URBAN RUNOFF POLLUTANTS

Atmospheric processes affecting urban runoff pollutants include dry dustfall and precipitation quality. These two elements have been monitored in many urban and rural areas. In many instances, however, the samples were combined as a bulk precipitation sample before processing. Automatic precipitation sampling equipment currently available can automatically distinguish between dry periods of fallout and precipitation. These devices cover and uncover appropriate collection jars exposed to the atmosphere. As part of the Nationwide Urban Runoff and Atmospheric Deposition Programs of the EPA, much of this information is currently being collected. The USGS report (Ebbert, Poole, and Payne, 1983) discusses the Bellevue atmospheric deposition rates.

One must be very careful in interpreting this information, however, because of the ability of many polluted dust and dirt particles to be resuspended and then redeposited within the urban area. In many cases, the measured atmospheric deposition measurements include material that was previously residing and measured in other urban runoff pollutant source areas. Therefore, mass balances and determinations of urban runoff deposition and accumulation from different source areas can be highly misleading, unless transfer of material between source areas and the effective yield of this material to the receiving water is considered.

Dustfall and precipitation affect all of the major urban runoff source areas in an urban area. Dustfall, however, is typically not a major pollutant source but is mostly a mechanism for pollutant transport. Most of the dustfall monitored in an urban area is resuspended particulate matter from street surfaces or wind erosion products from vacant areas. Point source pollutant emissions can also significantly contribute to dustfall pollution. The bulk of the dustfall, however, is contributed by the other major pollutant sources. Barkdoll, et al (1977) stated that urban runoff contaminants may be moved by man's activities or the wind. Wind-transported materials are commonly called "dustfall". Dustfall includes sedimentation, coagulation with subsequent sedimentation and impaction. Dustfall is normally measured by collecting dry samples, excluding rainfall and snowfall. If rainout and washout are included, one has a measure of total atmospheric fallout. This total atmospheric fallout is sometimes called "bulk precipitation". Rainout removes contaminants from the atmosphere by condensation processes in clouds, while washout is the removal of contaminants by the falling rain. Therefore, precipitation can include natural contamination associated with condensation nuclei in addition to collecting atmospheric pollutants as the rain or snow falls. In some areas,

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the contaminant contribution by dry deposition is small, compared to the contribution by precipitation (Malmquist 1978). However, in heavily urbanized areas, dustfall can contribute more of an annual load than the wet precipitation, especially when dustfall includes resuspended materials.

Rain water quality has been reported by several researchers. As expected, the non-urban area rain quality can be substantially better than urban rain quality. Many of the important heavy metals, however, have not been detected in rain in many areas of the country. The most important heavy metals in rain in urban areas are lead and zinc, both being present in rain up to several hundred ug/l. The concentrations of lead and zinc in non-urban areas is typically less than 50 ug/l. Iron is also present in relatively high concentrations in rain (about 30 to 40 ug/l).

The concentrations of various important urban runoff pollutants in dry dustfall has also been studied. Urban, rural and oceanic dry dustfall samples contain more than 5,000 mg iron/kg total solids. Zinc and lead are the next most predominant constituents of dustfall in urban areas. These can be several thousand mg/kg dry dustfall. Spring, et al (1978) monitored dry dustfall near a major freeway in Los Angeles, California. Based on a series of samples collected over several months, they found that lead concentrations on and near the freeway can be about 3,000 mg/kg, but as low as about 500 mg/kg 500 feet (150 meters) away. In contrast the chromium concentrations of the dustfall did not vary substantially between the two locations and approached oceanic dustfall chromium concentrations.

Much of the monitored atmospheric dustfall and precipitation would not reach the urban runoff receiving waters. The percentage of dry atmospheric deposition retained in a rural watershed was extensively monitored and modelled in Oakridge, Tennessee (Barkdoll, et al, 1977). They found that about 98 percent of the dry atmospheric deposition lead was retained in the watershed, along with about 95 percent of the cadmium, 85 percent of the copper, 60 percent of the chromium and magnesium and 75 percent of the zinc and mercury. Therefore, if the dry deposition rates were added directly to the yields from other urban runoff pollutant sources, the resultant urban runoff loads would be very heavily over-estimated.

Chemical oxygen demand (COD) is the largest component in bulk precipitation, followed by total dissolved solids (TDS) and suspended solids (SS). Betson (1978), in a study in Knoxville, Kentucky, found that almost all of the pollutants in the urban runoff streamflow outputs could easily be accounted for by bulk precipitation deposition alone. Betson concluded that bulk precipitation is an important component for some of the constituents in urban runoff but the transport and resuspension of particulates from other areas in the watershed are overriding factors.

RESUSPENSION OF SOURCE AREA PARTICULATES

Rubin (1976) stated that resuspended urban particulates are returned to the earth's surface and water bodies in four main ways: gravitational settling, impaction, precipitation and washout. Gravitational settling, as dry deposition, returns most of the particles. This not only involves the settling of relatively large fly ash and soil particles, but also the settling of smaller particles that collide and coagulate. Rubin stated that particles that are less than 0.1 micron in diameter move randomly in the air and collide often with other particles. These small particles can then grow rapidly by this coagulation process. These small particles would soon be totally depleted in the air if they were not constantly replenished. Particles in the 0.1 to 1.0 micron range are also removed primarily by coagulation. These larger particles grow more slowly than the smaller particles because they move less rapidly in the air, are somewhat less numerous and, therefore, collide less often with other particles. Particles with diameters larger than one micron have appreciable settling velocities. Those particles about ten microns in diameter can settle rapidly, although they can be kept airborne for extended periods of time and large distances by atmospheric turbulence. The second important particulate removal process from the atmosphere is impaction. Impaction of particles near the earth's surface can occur on vegetation, rocks and building surfaces. The third form of particulate removal from the atmosphere is precipitation, in the form of rain and snow. This is the rainout process described earlier where the particulates are removed in the cloud-forming process. The fourth important removal process is washout of the particulates below the clouds during the precipitation event. Therefore, it is easy to see that reentrained particles (especially from street surfaces, other paved surfaces, rooftops and from soil erosion) in urban areas can be readily redeposited through these various processes, either close to the points of origin or at some distance downwind.

Pitt (1979) monitored roadside concentrations of particulates. He found that on a number basis, the downwind roadside particulate concentrations were about 10 percent greater than upwind conditions. About 80 percent of the concentration increases, by number, were associated with particles in the 0.5 to 1.0 micron size range. However, about 90 percent of the particle concentration increases by weight were associated with particles greater than ten microns. He found that the rate of particulate resuspension from street surfaces increases when the streets are cleaned at long intervals and varies widely for different street and traffic conditions. The resuspension rate was calculated based upon observed long-term accumulation conditions on street surfaces from many different study area conditions and varied from about one to 12 lbs/curb-mile/day (0.3 to 3.4 g/curb-meter/day).

Murphy (1975) described a Chicago study where airborne particulate material within the city was microscopically examined, along with street surface particulates. The particulates (mostly limestone and quartz) from both of these areas were found to be similar in nature indicating that the airborne particulates were most likely resuspended street surface particulates. PEDCo (1977) found that the reentrained portion of the traffic-related particulate emissions (by weight) is an order of magnitude greater than the direct emissions accounted for by vehicle exhaust and tire wear. They also found that particulate resuspensions from a street are directly proportional to the traffic volume and that the suspended particulate concentrations near the streets are associated with relatively large particle sizes. The medium particle size found, by weight, was about 15 microns, with about 22 percent of the particulates occurring at sizes greater

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than 30 microns. These relatively large particle sizes resulted in substantial particulate fallout near the road. They found that about 15 percent of resuspended particulates fall out at 10 meters, 25 percent at 20 meters and 35 percent at 30 meters from the street (all percentages are expressed by weight). In a similar study Cowherd, et al (1977), reported a wind erosion threshold value of about 13 miles per hour (21 kilometers per hour). At this wind speed, or greater, significant dust and dirt losses from the road surface could result, even in the absence of traffic-induced turbulence. Rolfe and Reinbold (1977) also found that most of the particulate lead from automobile emissions falls out within 100 meters of roads. However, the automobile lead widely disperses over a large area. They found, through multi-elemental analyses, that the settled outdoor dust collected at or near the curb was contaminated by automobile activity and originated from the streets. Soil samples taken near buildings that were painted with lead base paint were contaminated by lead from chipping paint.

APPENDIX H

REACTIONS AND FATES OF IMPORTANT URBAN RUNOFF POLLUTANTS

This section of the report summarizes information from the literature on chemical reactions, solubilities and fates of important urban runoff pollutants. Rubin (1976) discussed the forms and reactions that may occur for heavy metals. Metals in natural waters may be soluble, colloidal or suspended. Soluble metals are defined as being less than one micron in size, while suspended metals are greater than 100 microns in size. Colloidal metals are intermediate in size. Using these definitions, settleable materials are also included in the suspended size fraction. Rubin further stated that the suspended and colloidal particles may consist of individual or mixed metals in the form of their hydroxides, oxides, silicates, sulfides or as other compounds. They may also consist of clay, silica or organic matter to which metals are bound by adsorption or ion exchange or as a complex. The soluble metals may be un-ionized organo-metallic chelates, organic ions, or complexes of these chelates or ions. Because of various reactions within the water, (physical, chemical or biological) there may be dynamic interactions among the various particle sizes and chemical forms. When incoming metals react with receiving water bodies, several types of potential interactions can take place. The pH and Eh (oxidation reduction potential, redox potential or ORP) are very important in controlling solubility and agglomeration and, therefore, sedimentation of a metal. The pH of the water system also affects the bonding of the metals to insoluble carriers which influences adsorption, ion exchange and co-precipitation.

The oxidation reduction potential can also radically affect the ionic form of the metal. Iron and manganese are the most responsive metals to Eh exchanges with lower redox potentials favoring the divalent (+2) iron and manganese valence states. These valence states are also much more soluble than the more oxidized (+3) states. Redox potential and pH will both affect the stability of certain transition metal chelates (Rubin 1976).

The presence of inorganic ions can form complexes with the metals that can increase the solubility of the metals. As an example, as salinity is increased, more manganese becomes dissolved rather than suspended. The opposite can happen with other complexes, where metal carbonates and sulfides typically have limited solubilities. Organic complexing agents in natural waters include humic and fulvic acids. These can form stable metal humics and fulvics that are soluble in fresh waters. Adsorption and ion exchange can also bind metals to insoluble particulates, especially in flowing waters with large quantities of clay and soil. Much of the material that the metals interact with involve organic materials that originated from aquatic organisms. Other aquatic organism effects on metal solubilities include changes in pH and Eh by various biochemical processes. These in turn affect soluble metal concentrations and metal accumulations in sediments. Aquatic organisms can also concentrate many metals in their tissues (bioaccumulation).

Rubin (1976) also discussed the importance of oxidation reduction reactions at the sediment-water interface. This interface can have a large Eh gradient depending upon the mixing, diffusion and the extent of biological activity. Intense redox activity can occur at the sediment-water interface because of deposition and accumulation of organic matter: diffusion of oxygen down into the sediment interstitial waters can then create a large redox gradient. Organic sediments generally contain large quantities of reduced material, especially sulfides. Since most heavy metal sulfides tend to be rather insoluble, it is clear that interactions in the heterogeneous sulfide systems can be an important process where trace metals are retained or released from the soluble phase (Rubin 1976).

Gambrell and Patrick (1977) stated that metals are present in soils and sediments in many chemical forms that differ greatly in their bioavailability. Some metals are bound within the crystalline structure of the sediments and soils and are essentially unavailable to biota. However, metals dissolved in soil solutions, or in interstitial or surface waters, are considered readily available to biota. Also, metals weakly adsorbed to the solid mineral or organic colloidal phase by ionic exchange mechanisms are also readily available. Between the unavailable and readily available metals forms are a number of forms that are potentially available. As discussed previously, the potential solubility, and therefore availability, of various metal forms are strongly dependent upon the pH and oxidation reduction conditions and, of course, the specific chemical compound. In reduced sediment conditions, the formation of stable and insoluble metal sulfide precipitates is important in limiting the mobility and bioavailability of most metals. Humic materials in reduced environments are characterized by large molecular weights and greater structural complexity. These characteristics increase the metal retention capacity and the metal bonding stability of insoluble humic materials. If these reduced sediments are subjected to an oxidizing environment, such as being aerated by dredging, scouring during high flows or by benthic organism activities, many of these insoluble organics are more likely to become soluble. This is especially true for copper, lead and cadmium complexes. As an example, Gambrell and Patrick found that as the redox potential was increased from strongly reducing to well oxidized levels, insoluble organic bound cadmium was transferred to more available soluble and exchangable forms. They also stated that a reduction in metal availability by the formation of insoluble organic complexes in reduced sediments, may be offset to some extent by an increase in soluble or organic acids which maintain some metals in solution as soluble organic complexes. These various Eh and pH mechanisms affect various metal complexes differently. As an example, lead solubility is enhanced by low pH levels but is little affected by changes in oxidation reduction conditions.

Callahan, et al (1979), described the importance of various environmental processes for the aquatic fates of some urban runoff heavy metals and organic priority pollutants. Photolysis (the breakdown of compounds in the presence of sunlight) and volatilization (the transfer of material from the water into the air as a gas or vapor) are not nearly as important as the other mechanisms for heavy metals. Chemical speciation (the formation of chemical compounds) is very important in determining the solubilities of the specific metals. Sorption (adsorption is the attachment of the material on to the outside of a solid and absorption is the attachment of the material within a solid) is very important for many heavy metals. Sorption can typically be the controlling mechanism affecting the mobility and the precipitation of most heavy metals. Bioaccumulation (the uptake of the material into organic tissue) can also occur for many heavy metals. Biotransformation (the change of chemical form of the metal by organic processes) is very important for some metals, especially mercury, arsenic and lead. In many cases, the discharge of mercury, arsenic or lead compounds in forms that are unavailable can be accumulated in aquatic sediments. They are then exposed to various benthic organisms that can biotransform the material through metabolization to methylated forms of the material which can be highly toxic and soluble. Various organic priority pollutants are also found in urban runoff, mainly various phenols, polycyclic aromatic hydrocarbons (PAHs) and phthalate esters. Photolysis may be an important fate process for phenols and PAHs but is probably not important for the phthalate esters. Oxidation or hydrolysis may be important for some phenols. Volatilization may be important for some phenols and PAHs. Sorption is an important fate process for most of the materials, except for phenols. Bioaccumulation, biotransformation and biodegradation are important processes for many of these organic materials.

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